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CALCULATION METHODS FOR CRITERIA AIR POLLUTANT EMISSION INVENTORIES

ARMSTRONG LABORATORY

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This report serves as a guidance manual for Bioenvironmental Engineering personnel or other, responsible environmentally-related office in the development of installation-level criteria air pollutant emission inventories. Emission inventories are used to assess and document compliance with federal, state, and local environmental statutes and regulations and can serve as a useful pollution management tool. This report may be used in a stand-alone fashion or in conjunction with an Air Staff-approved emissions software database management program tailored for the Air Force community. Source-specific emissions software, available through the U.S. Environmental Protection Agency for some sources such as motor vehicles and fuel storage tanks, may also be used to assist in calculating and managing emissions data.

14. SUBJECT TERMS
Emission Inventory Emission Factor Criteria Air Pollutants Particulate Matter Volatile Organic Compounds Ozone Carbon Monoxide Nitrogen Oxides Sulfur Oxides

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SECTION I

INTRODUCTION

A. BACKGROUND

The 1970 Clean Air Act Amendments established National Ambient Air Quality Standards (NAAQS) for those pollutants determined to present a significant and immediate threat to the public health and welfare. Primary and Secondary standards were established for what are commonly referred to as the "criteria pollutants": carbon monoxide, ozone, nitrogen oxides, sulfur oxides, particulate matter, and lead. Those areas (typically counties) which meet the NAAQS are considered to be "in attainment", while areas that are above the NAAQS for a particular pollutant are considered to be in "nonattainment" for that pollutant. Strategies contained within the framework of the 1970 Clean Air Act and 1977 Clean Air Act Amendments to bring urban areas to within attainment status resulted in limited successes; much of this do to industry expansion and a steady increase in the number of mobile sources and miles traveled. The presence of unacceptably-high ambient air pollutant levels in many urban areas persist. This continuing dilemma and the public's ever-increasing awareness and concern over environmental issues have become the driving force behind the extensive and far-reaching 1990 Clean Air Act Amendments (CAAA-90).

B. PURPOSE

Air pollutant emission inventories are integral to the nation's overall pollution control and reduction strategy. Air Force policy and guidance documents, including Air Force Instruction 48-119, require that air emission inventories be compiled and maintained to the degree required by federal, state and local regulatory agencies. With the advent of the 1990 Clean Air Act Amendments, Air Force installations have come under increased scrutiny. State agencies are routinely requesting submittal of updated, comprehensive air emission inventories.

The criteria pollutant emission inventory can be used to assess regulatory compliance, specifically:

- Clean Air Act
- State Permitting Programs
- National Environmental Policy Act (environmental assessments & impact statements)

The criteria pollutant emission inventory can serve as a useful pollution management tool:

- Emission Reduction Credits
- Risk Assessments
- Pollution Prevention Programs
- Environmental Self-Audit

C. SCOPE:

This reference encompasses only criteria pollutants (those for which there are National Ambient Air Quality Standards), and does not apply to the air toxics provisions (Title III) of the CAAA-90 which concern the regulation of an additional 189 hazardous air pollutants (HAPs). Lead, which is both a criteria and hazardous air pollutant, is not addressed in this manual. Lead is no longer the significant pollutant it was prior to the transition to unleaded fuels, which dramatically reduced airborne levels nation-wide.

This guidebook was specifically developed to provide environmental personnel the means to manually compute and compile a thorough emissions inventory of their installation's mobile, area, and stationary point sources. It was designed for relative ease of use by those in environmentally-related career fields, including Bioenvironmental and Civil Engineers and qualified technicians.

This reference may be used alone or in conjunction with an approved emissions software database management program. Currently, two programs are approved for Air Force use: Air Force Air Emission Compliance Tracking System (AFAECTS) and Air Quality Utility Information System (AQUIS). As of this writing, the Department of Defense (DOD) is evaluating the selection of a single, comprehensive program to facilitate similar calculating, management, and reporting methods DOD-wide.

Sources for AFAECTS/AQUIS and other resources that may be helpful are located in Appendix A. Information concerning emissions inventories and compliance (e.g., regulatory revisions, new methodologies and emission factors, updated software, etc.) will be provided, as it becomes available, in the Armstrong Laboratory Occupational and Environmental Health Directorate Newsletter. Questions concerning air emissions should be directed to the Armstrong Laboratory Air Quality Branch, DSN 240-3305 or FAX DSN 240-3945.

SECTION II

METHODOLOGY

Only specific source sampling measurements can determine the actual pollutant contribution from a source, under conditions existing at the time of the test. The large number of individual sources, diversity of source types, and the cost/manpower required makes conducting field measurements of emissions impractical on a source-by-source basis. The only feasible method of determining pollutant emissions for a given community or installation is to make general emission estimates typical of each source type. An *Emissions Inventory* is a compilation of these emission estimates over a given period, typically a year. When available, measurement data derived from surveys (e.g., stack sampling) should also be incorporated into the inventory.

Emission estimations are determined by means of "emission factors" which are average values relating the quantity of a pollutant released to the atmosphere with the activity associated with its release. An emission factor is usually expressed as the weight of pollutant per unit weight, volume, distance, or duration of the activity that emits the pollutant.

Formulas for the purpose of accomplishing emission estimations for those sources specific to Air Force installations and their operations are contained within this manual. Basic procedures for conducting an emissions inventory are summarized below.

- Identify all sources of air pollution on the installation.

- Determine the fuel (or other product) type and its consumption rate (per unit distance or time period) for each source or source type.

- Determine the total number of events per unit of time.

- Calculate the emissions for each pollutant for each source or source type using the formulas and emission factors given within the appropriate section of this manual.

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(U.S.) Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources (AP-42), 4th Ed., Sup. A-E. Research Triangle Park NC, October 1992.

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SECTION III

CRITERIA POLLUTANT SUMMARY

There are two types of air quality standards. *Primary* Standards were established to protect the public from adverse health effects. *Secondary* Standards were established for general "welfare" purposes, such as damage to farm crops and vegetation, and deterioration of buildings and other structures such as monuments.

Principal sources of air pollution on Air Force installations include: motor vehicles, aircraft, aerospace ground equipment (AGE), central heat and power plants, incinerators, generators, heating systems, fuel storage areas, solvent cleaning and surface coating operations, firefighting training, and hazardous material spills.

Carbon Monoxide: Carbon monoxide (CO) is a colorless, odorless, poisonous gas that inhibits blood/oxygen transfer. It is a product of incomplete combustion and is considered the most common and widely distributed pollutant. CO is produced by virtually all combustion processes in varying amounts relative to the combustion efficiency of the process. Sources of CO emissions on Air Force installations include mobile sources (i.e., aircraft, motor vehicles), boilers/furnaces, and incinerators.

Ozone: Unlike the other pollutants, ozone (O_3) is not emitted directly into the air. It is created by sunlight acting upon the precursors volatile organic compounds (VOCs) and, to a lesser extent, nitrogen oxides. Ozone--the primary constituent of smog--aggravates respiratory conditions, irritates the eyes and mucous membranes, and reduces visability. VOC emission sources include the storage, transfer, and burning of hydrocarbon (HC) fuels and organic solvent operations, such as cleaning and surface coating processes. The EPA's definition of VOCs does not include methane, ethane, methylene chloride, 1,1,1-trichloroethane, hydrochlorofluorocarbons (HCFCs), and chlorofluorocarbons (CFCs). These materials do not contribute to ozone formation. The complete definition of VOCs can be found at 40 CFR 51.100.

Nitrogen Oxides: The primary nitrogen oxides (NO_x) of importance are nitric oxide (NO) and nitrogen dioxide (NO_2). A product of high temperature combustion of fossil fuels, they are poisonous and contribute to the formation of tropospheric ozone (smog) and acid rain. Combustion processes utilizing natural gas, coal, residual fuels (grades 4/5/6), and aviation fuel are principal producers of NO_x.

Sulfur Oxides: Sulfur is a component of fossil fuels released to the atmosphere in the form of sulfur dioxide (SO_2) and sulfur trioxide (SO_3) during combustion. Primary effects include irritation of the upper respiratory tract and eyes, damage to vegetation, and structural deterioration. SO_3 is primarily responsible for "acid rain" production. Coal-fired central heating and power plants are the largest single source of sulfur oxides (SO_x) on installations. Processes utilizing heavy residual fuels and aviation fuels are also major SO_x producers.

Particulate Matter: Particulate Matter (PM) includes both solids and liquids suspended in the atmosphere and is commonly in the form of dust, soot, fly ash, fumes, and fog. PM reduces visibility and causes soiling. Its interaction with other pollutants such as SO_x can result in greater harmful effects to health, vegetation, and structures than what would be caused by each pollutant acting independently. Recent studies indicate PM aggravates respiratory ailments and point to a correlation between PM and increased death risk to those with respiratory disorders. Typically, only PM with an aerodynamic diameter less than or equal to 10 micrometers (PM_{10}) is regulated. Whenever possible, both PM and PM_{10} emission factors are provided in this manual.

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(U.S.) Environmental Protection Agency. Air Quality Atlas. Research Triangle Park NC, May 1992.

SECTION IV

COMPILING THE AIR EMISSION INVENTORY

A. INCINERATORS

1. BACKGROUND

a. Air Force installations typically utilize what EPA describes as industrial/commercial combustors. Municipal waste combustors, used for the disposal of very large amounts of diverse refuse, are generally not operated on Air Force installations.

b. The following two industrial/commercial combustors are most common to Air Force bases:

(1) Classified Waste Incinerator: operated by communication organizations and Wing/Base Headquarters.

(2) Medical (or hospital) Waste Incinerator: used to burn biological refuse items, laboratory and pharmaceutical chemicals and containers, and pathological wastes (all of which may contain infectious waste material). This type should not be confused with the less common "Pathological" Waste Incinerator, which is strictly designed and authorized for pathological wastes only.

c. Most classified waste and medical waste incinerators are of the multiple chamber type and are usually distinguished by mode of operation:

(1) Batch-Feed: typically a small unit, up to 500 lb/hr, but generally less than 200 lb/hr. Operated in a "batch mode" over a 12 to 24-hour period beginning with a single charge; usually loaded manually.

(2) Intermittent-Duty: Can accommodate multiple charges throughout the operating cycle, but must be shut down on a cycle for ash removal. Manual or automated charging systems may be used.

(3) Continuous-Duty: Can be operated at a near-steady-state condition because it has the capability of continuously removing the ash from the hearth. Charging/ash removal is conducted at regularly timed intervals.

2. CALCULATIONS: The following equation is used:

$$E = MF$$

Where:

E = Emissions of a particular pollutant (lb/yr)
M = Mass of waste burned per year (ton/yr) *Note* - for batch-feed incinerators, **M** may be estimated by multiplying the average weight of waste charged per burn by the number of burns per year.
F = Pollutant emission factor (lb/ton) from tables A-1 and A-2

3. EXAMPLE PROBLEM: Calculate the annual emissions generated by a batch-feed, multiple-chamber medical waste incinerator used for 156 burns over the past year; each burn averaging 50 lbs (.025 tons) of waste.

POLLUTANT	WASTE BURNED (ton/burn)	x	BURNS/YR	x	EMISSION FACTOR (lb/ton)	=	TOTAL EMISSIONS (lb/yr)
CO	.025		156		10		39.0
VOC	.025		156		3		11.7
NO_x	.025		156		3		11.7
SO_x	.025		156		2.5		9.8
PM	.025		156		7		27.3

TABLE A-1
UNCONTROLLED EMISSION FACTORS FOR
INDUSTRIAL/COMMERCIAL INCINERATORS[a] (lb/ton)

INCINERATOR TYPE	CO	VOC[b]	NO_x[c]	SO_x[d]	PM
Multiple Chamber	10	3	3	2.5	7
Single Chamber	20	15	2	2.5	15
Pathological[e]	8	Neg[f]	3	Neg	Neg

[a]Factors are averages based on EPA procedures for incinerator stack testing.
[b]Expressed as methane.
[c]Expressed as NO_2.
[d]Expressed as SO_2.
[e]EPA defines pathological wastes as tissues, organs, body parts, blood, and body fluids removed during surgery, autopsy, biopsy.
[f]Negligible.

TABLE A-2
EMISSION FACTORS FOR
MUNICIPAL WASTE COMBUSTION (lb/ton)

	MASS BURN		STARVED AIR		RD[a] FUEL	
POLLUTANT	No Control	Control	No Control	Control	No Control	Control
CO	2.2	2.2[b]	3.4	3.4[d]	3.6	3.6[c]
VOC	0.0064	0.0064[c]	N/A	N/A	N/A	N/A
NO_x	3.6	3.6[d]	4.4	4.4[d]	5.0	5.0[d]
SO_2[e]	1.7	1.1[b]	1.7	1.1[b]	1.7	1.1[b]
PM	38	0.38[c]	1.9	0.030[c]	80	0.08[d]
PM_{10}	14	0.18[c]	1.4	0.024[c]	44	0.74[d]

[a]Refuse-Derived.
[b]Control devices include Electrostatic Precipitator (ESP), Fabric Filter (FF), dry scrubbers, and wet scrubbers.
[c]Control devices include ESP and FF.
[d]Control device is an ESP.
[e]Average for all three combustor types.

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(U.S.) Environmental Protection Agency. Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources (AP-42), 4th Ed., Sup. A-E. Research Triangle Park NC, October 1992.

Fagin, G.T. Manual Calculation Methods for Air Pollution Inventories. USAFOEHL-88-070EQ0111EEB, May 1988.

B. BOILERS AND FURNACES

1. BACKGROUND

a. A significant portion of the pollutant emissions generated by Air Force installations comes as a direct result of their large heating and power production requirements. The impact each source has toward contributing to the overall emission load relies upon the fuel type, amount consumed, design and condition of the combustion system, and whether the system is being operated properly. Improper operation and maintenance can result in inadequate fuel/air mixing, insufficient operating temperatures, and other problems; resulting in significant NO_x, CO, VOC, and PM emissions.

b. Fuels:

(1) Coal combustion is sometimes used in large industrial heat and power production operations and is the largest single contributor to acid rain" formation. Coal is classified by its heating value and amount of fixed carbon, volatile matter, ash, sulfur, and moisture. Anthracite is considered the "cleanest" type due to its low sulfur and volatile matter content; however, bituminous and subbituminous coal are more available and less costly.

(2) Fuel oils are classified as distillates and residuals. Distillate oils (fuel oil grade Nos. 1 and 2) are used primarily in domestic and small commercial applications. They are more volatile and produce less ash, sulfur, and nitrogen than the heavier residuals (grade Nos. 4, 5, and 6) which are used mainly in utility, industrial and large commercial operations.

(3) Natural gas is used for power generation, industrial process steam, and domestic and commercial space heating. The primary component is methane, with varying amounts of ethane, propane, butane, and inerts (helium, nitrogen, and carbon dioxide). Note that EPA's definition of volatile organic compounds does not include methane and ethane because they have been shown not to be photochemically reactive. Natural gas is considered to be a relatively clean-burning fuel. Pollutant emissions are primarily due to improper combustion reaction associated with operation and maintenance practices.

(4) Liquified petroleum gas (LPG) consists of butane, propane, or a mixture of the two. LPG is considered a clean fuel because of no visible emissions. But as with natural gas, interferences with proper combustion can result in significant pollutant emissions including NO_x, CO, and VOCs.

c. Furnace/Boiler Systems: Although a furnace is actually part of a boiler system, the two terms are sometimes used interchangeably.

(1) Coal-fired systems are categorized by mode of operation:

Pulverized Coal Furnace (dry or wet bottom)
Cyclone Furnace
Spreader Stoker
Overfeed Stoker
Underfeed Stoker

Two major combustion processes are employed. Suspension firing is used in pulverized and cyclone furnaces. Grate firing is associated with overfeed and underfeed systems. Both combustion mechanisms are used in spreader stokers.

(2) Fuel oil, natural gas, and LPG systems are categorized by their gross heat rate in million Btu per hour (10^6 Btu/hr). These categories include the following:

Utility Boilers -	$>100 \times 10^6$ Btu/hr
Industrial Boilers -	10 to 100×10^6 Btu/hr
Commercial Boilers -	0.5 to 10×10^6 Btu/hr
Residential Furnaces -	$<0.5 \times 10^6$ Btu/hr

2. CALCULATIONS: The Civil Engineering organization is the primary source for information on type, number, and location of combustion systems. Supply Fuels may be the best source for fuel usage rates. Coal-fired systems are limited to central heating and power plants, and assessing the emissions is relatively easy. However, there may be many fuel oil, LPG, or natural gas-fired systems on the installation. For these sources, emissions can be calculated accumulatively by combining similar systems and their fuels; but this should be done carefully. For example, a tangentially-fired utility boiler and a vertical-fired utility boiler generate significantly different amounts of NO_x, although other pollutant emission factors may be the same. Similarly, an industrial boiler using grade 6 fuel oil cannot be categorized with one fired by grade 5 due to each fuel's differing sulfur content. Simply, those systems being categorized together must have the same emission factors for all pollutants and identical particulate controls (if any). Scrutinize the emission factor tables carefully when making these determinations. The following equation is used:

$$E = CFR^*$$

Where:

E = Emissions of a particular pollutant (lb/yr)
C = Fuel consumption (e.g., ton/yr, 10^6 ft^3/yr, 10^3 gal/yr)
F = Emission factor (e.g., lb/ton, lb/10^6 ft^3, lb/10^3 gal)
R = Control reduction factor (1 - % control efficiency/100

***Note - R available for PM only. See Table B-1 for control efficiencies.**

3. EXAMPLE PROBLEMS:

a. Calculate the annual emissions of a heating plant whose dry bottom boilers burn pulverized bituminous coal containing a yearly average of 1.5% sulfur and 5% ash (by weight, as fired). Multiple cyclone separators are used to control particulates.

POLLUTANT	FUEL CONSUMPTION (ton/yr)	x	EMISSION FACTOR (lb/ton)	x	CRF	=	ANNUAL EMISSIONS (lb/yr)
CO	25,000		0.6		---		15,000
VOC	25,000		0.07		---		1,750
NO_x	25,000		21		---		525,000
SO_x	25,000		58.5		---		1,462,500
PM	25,000		10(5)		0.2		250,000
PM_{10}	25,000		0.58(5)		---		72,500

b. Calculate the annual emissions generated by all grade 6 (residual) fuel oil industrial boilers on a given installation which are not equipped with particulate control devices. The fuel oil contains 0.9% sulfur. All boilers are being properly operated and maintained and are judged to be operating efficiently.

POLLUTANT	FUEL CONSUMPTION (10^3 gal/yr)	x	EMISSION FACTOR (lb/10^3 gal)	=	ANNUAL EMISSIONS (lb/yr)
CO	52.2		5		261
VOC	52.2		0.28		14.6
NO_x	52.2		55		2871
SO_x	52.2		159.9(0.9)		7512.1
PM	52.2		12		626.4
PM_{10}	52.2		12(0.86)		538.7

TABLE B-1 CONTROL EFFICIENCIES FOR TOTAL PARTICULATES (PM)				
	Multiple Cyclone	Scrubber	ESP	Baghouse
Efficiency Rating	80%	94%	99.2%	99.8%

ESP = Electrostatic Precipitator

TABLE B-2 BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION UNCONTROLLED EMISSION FACTORS (lb/ton)						
Firing Configuration	CO[a]	VOC[a,b]	NO_x[c]	SO_x[d]	PM[e]	PM_{10}[e]
Pulverized Dry Bottom	0.6	0.07	21(15)[f]	39S(35S)	10A	2.3A
Pulverized Wet Bottom	0.6	0.07	34	39S(35S)	7A[g]	2.6A
Cyclone Furnace	0.6	0.07	37	39S(35S)	2A[g]	.26A
Spreader Stoker	5	0.07	14	39S(35S)	60[h]	12
Overfeed Stoker[i]	6	0.07	7.5	39S(35S)	16[j]	6
Underfeed Stoker	11	1.3	9.5	31S	15[k]	6.2

[a]Values one or two orders of magnitude higher can occur when combustion is not complete.
[b]Nonmethane volatile organic compounds, expressed as C_2 to C_{16} n-alkane equivalents.
[c]Expressed as NO_2. Generally, 95 - 99 volume % of nitrogen oxides present in combustion exhaust will be in the form of NO, the rest NO_2. To express factors as NO, multiply by factor of 0.66.
[d]Expressed as SO_2, including SO_2, SO_3, and gaseous sulfates. Number in parentheses is used to estimate gaseous SO_x emissions for subbituminous coal. "S" indicates that weight % sulfur (as fired) should be multiplied by the given value. For example, if bituminous coal containing 1.5% sulfur is fired in a cyclone furnace, the SO_x emission factor would be 39 x 1.5, or 58.5 lb/ton. On average for bituminous coal, 97% of fuel sulfur is emitted as SO_2, about 0.7% is emitted as SO_3 and gaseous sulfate.
[e]Based on EPA Method 5 (front half catch). Where particulate is expressed in terms of ash content "A", factor is determined by multiplying % weight ash content of coal (as fired) by the numerical value preceding the "A". For example, if coal having 8% ash content is fired in a dry bottom unit, the particulate emission rate would be 10 x 8, or 80 lb/ton.
[f]Parenthetic value is for tangentially fired boilers.
[g]Uncontrolled particulate emissions, when no fly ash reinjection is employed. When control device is installed and collected fly ash is reinjected to boiler, particulate from boiler reaching control equipment can increase by up to a factor of two.
[h]Accounts for fly ash settling in an economizer, air heater, or breeching upstream of control device or stack (PM directly at boiler outlet typically will be twice this level). Apply factor even when fly ash is reinjected from boiler to boiler, air heater, or economizer hoppers.
[i]Includes traveling grate, vibrating grate, and chain grate stokers.
[j]Accounts for fly ash settling in breeching or stack base. Particulate loadings directly at boiler outlet typically can be 50% higher.
[k]Accounts for fly ash settling in breeching downstream of boiler outlet.

TABLE B-3 BITUMINOUS AND SUBBITUMINOUS COAL COMBUSTION CONTROLLED PM_{10} EMISSION FACTORS (lb/ton)				
Firing Configuration	Multiple Cyclone	Scrubber	ESP	Baghouse
Pulverized Dry Bottom	0.58A	0.42A	0.05A	0.02A
Pulverized Wet Bottom	1.3A	---	0.042A	---
Cyclone Furnace	---	0.112A	0.011A	---
Spreader Stoker	12.4	7.8	0.44	0.072
Overfeed Stoker	5.0	---	---	---

*Where particulate is expressed in terms of ash content "A", factor is determined by multiplying % weight ash content of coal (as fired) by the numerical value preceding the "A".

TABLE B-4 ANTHRACITE COAL COMBUSTION UNCONTROLLED EMISSION FACTORS (lb/ton)						
Boiler Type	CO	VOC	NO_x	SO_2[a]	PM[b]	PM_{10}
Stoker Fired Boilers	0.6	0.2	9.2	39S	0.98A	4.8
Pulverized Coal	0.6	0.07	18	39S	10A	2.3A
Hand-Fired	90	10	3	39S	10	5.2

[a]Emissions are mostly SO_2, with 1 - 3% SO_3. "S" indicates that % weight sulfur content of coal (as fired) should be multiplied by the value given.
[b]Where particulate is expressed in terms of ash content "A", factor is determined by multiplying % weight ash content of coal (as fired) by the numerical value preceding the "A".

TABLE B-5 ANTHRACITE COAL COMBUSTION CONTROLLED PM_{10} EMISSION FACTORS (lb/ton)		
Boiler Type	Multiple Cyclone	Baghouse
Pulverized Dry Bottom	1.10A	0.013A

*Where particulate is expressed in terms of ash content "A", factor is determined by multiplying % weight ash content of coal (as fired) by the numerical value preceding the "A".

TABLE B-6
FUEL OIL COMBUSTION
UNCONTROLLED EMISSION FACTORS ($lb/10^3$ gal)

Boiler Type	CO[a]	VOC[b]	NO_x[c]	SO_x[d]	PM[e]	PM_{10}
Utility Boiler						
Residual Oil	5	0.76	f	159.9S	g	PM x 0.71
Industrial Boiler						
Residual Oil	5	0.28	55[h]	159.9S	g	PM x 0.86
Distillate Oil	5	0.2	20	144S	2	1
Commercial Boiler						
Residual Oil	5	1.13	55	159.9S	g	PM x 0.62
Distillate Oil	5	0.34	20	144S	2	PM x 0.55
Residential Furnace						
Distillate Oil	5	0.713	18	144S	2.5	1.2

[a]CO emissions may increase by factors of 10 to 100 if the unit is improperly operated or poorly maintained.
[b]VOC emissions are generally negligible unless boiler is improperly operated or poorly maintained.
[c]Expressed as NO_2. Test results indicate that at least 95% by weight of NO_x is NO for all boiler types except residential furnaces (about 75% is NO).
[d]Expressed as SO_2. "S" indicates that the weight % of sulfur in the oil should be multiplied by the value given.
[e]Based on EPA Method 5 (front half catch).
[f]Use 42 $lb/10^3$ gal for tangentially fired boilers; 105 $lb/10^3$ gal for vertical fired boilers; and 67 $lb/10^3$ gal for all others, at full load and normal excess air (>15%). Several combustion modifications can be employed for NO_x reduction: (1) limited excess air can reduce NO_x emissions 5-20%; (2) staged combustion 20-40%; (3) using low NO_x burners 20-50%; and (4) ammonia injection can reduce NO_x emissions 40-70% but may increase emissions of ammonia. Combinations of these modifications have been employed for further reductions in certain boilers.
[g]Particulate emission factors for residual oil combustion are, on average, a function of fuel oil grade and sulfur content:

Grade 6 oil: 10 x % weight (S) of sulfur + 3 = $lb/10^3$ gal. This is based on 81 individual tests (correlation coefficient 0.65).
Grade 5 oil: 10 $lb/10^3$ gal
Grade 4 oil: 7 $lb/10^3$ gal

[h]NO_x emissions from residual oil combustion in industrial and commercial boilers are strongly related to fuel nitrogen content, estimated more accurately by the empirical relationship: lb $NO_2/10^3$ gal = 22 + $400(N)^2$ where N is the weight % of nitrogen in the oil. For residual oils having high (>0.5 weight %) nitrogen content, use 120 lb $NO_2/10^3$ gal as an emission factor.

TABLE B-7
FUEL OIL COMBUSTION
CONTROLLED PM_{10} EMISSION FACTORS (lb/ton)

Boiler Type	Multiple Cyclone	Scrubber	ESP
Utility Boiler			
Residual Oil	---	0.50A	0.042A
Industrial Boiler			
Residual Oil	1.58A	---	---

*Where particulate is expressed in terms of ash content "A", factor is determined by multiplying % weight ash content of coal (as fired) by the numerical value preceding the "A".

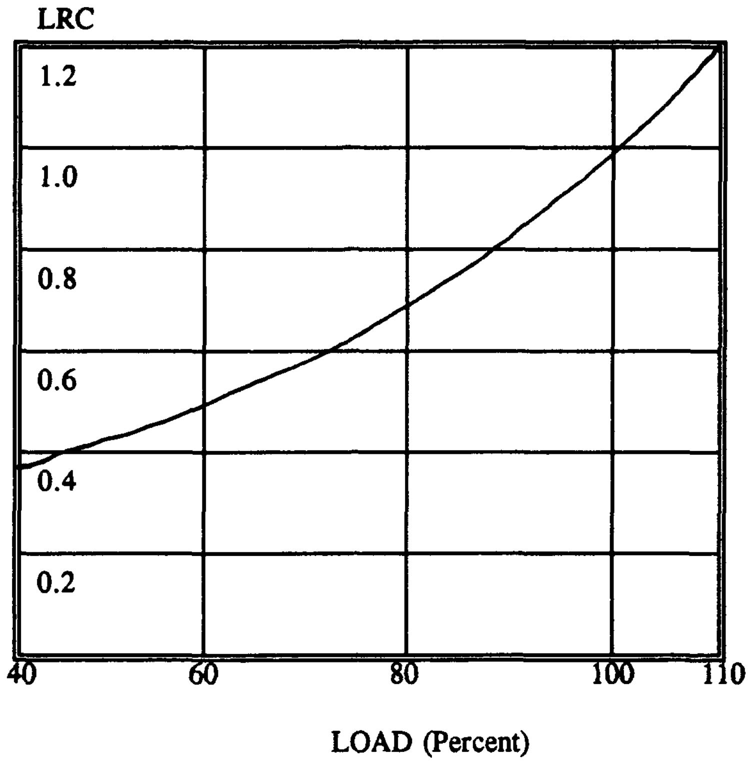
TABLE B-8 LPG COMBUSTION[a] UNCONTROLLED EMISSION FACTORS (lb/10^3 gal)					
Furnace Type and Fuel	CO	VOC	NO_x[b]	SO_x[c]	PM
Industrial					
Butane	3.6	0.6	21	0.09S	0.6
Propane	3.2	0.5	19	0.1S	0.6
Domestic/Commercial					
Butane	2.1	0.6	15	0.09S	0.5
Propane	1.9	0.5	14	0.1S	0.4

[a]Assumes emissions (except SO_x and NO_x) are the same, on a heat input basis, as for natural gas combustion. The NO_x emission factors have been multiplied by a correction factor of 1.5 which is the approximate ratio of propane/butane NO_x emissions to natural gas NO_x emissions.
[b]Expressed as NO_2.
[c]Expressed as SO_2. "S" indicates that the weight % of sulfur in the LPG should be multiplied by the value given.

TABLE B-9 NATURAL GAS COMBUSTION[a] UNCONTROLLED EMISSION FACTORS (lb/10^6 ft^3)					
Furnace Type and Size (10^6 Btu/hr heat input)	CO[b]	VOC	NO_x[cd]	SO_x[e]	PM/PM_{10}
Utility Boiler (>100)	40	1.4	550	0.6	3/3
Industrial Boiler (10 - 100)	35	2.8	140	0.6	13.7/3
Domestic and Commercial Boilers (<10)	21	5.3	100	0.6	12/3

[a]Expressed as weight/volume fuel fired.
[b]May increase 10 - 100 times with improper operation or maintenance.
[c]Expressed as NO_2. Tests indicate about 95% by weight NO_x is NO_2.
[d]At reduced loads, multiply factor by load reduction coefficient in Figure B-1.
[e]Expressed as SO_2. Based on average sulfur content of natural gas, 4600 g/10^6 Nm^3 (2000 gr/10^6 scf).

FIGURE B-1
LOAD REDUCTION COEFFICIENT (LRC) AS A
FUNCTION OF BOILER LOAD*



* Used to determine NO_x reductions at reduced loads.

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C. FIREFIGHTING TRAINING

1. BACKGROUND: Live firefighting proficiency training is performed particularly at those installations with flight operations. Live firefighting and rescue training is conducted in designated areas that may include aircraft mock-ups or fire pits which are doused with fuel or are fed by fuel dispensing systems. One or more fuels may be burned during training exercises including JP-4, JP-8, diesel, etc. Traditional methods of live fire training are becoming increasingly viewed as environmentally unacceptable and, under encouragement of the Air Staff, alternatives are being sought for new and existing facilities. Methods under consideration include the burning of liquid petroleum gas (LPG) with minimal amounts of jet fuel or other product being used for smoke effect.

2. CALCULATIONS: Emission factors exist only for JP-4. Although no specific emission factors for JP-8 exist, pollutant emissions should be comparable with those of JP-4 with the exception of smoke (PM), which will be somewhat higher. The installation's Fire Protection organization is the primary source for operational information. The following equation is used:

$$E = CDF$$

Where:

E = Emissions of a particular pollutant (lb/yr)
C = Fuel consumption (gal/yr) *Note* - multiply the number of burns/year by the average amount of fuel consumed per burn.
D = Density of fuel (lb/gal) *Note* - D = specific gravity of the fuel x 8.3.
F = Emission Factor (lb pollutant/lb fuel)

3. EXAMPLE PROBLEM: Calculate the annual emissions for a base that conducts 50 burns per year using an average of 75 gallons of JP-4 per burn.

POLLUTANT	BURNS (burns/yr)	x	FUEL BURNED (gal/burn)	x	FUEL DENSITY (lb/gal)	x	EMISSION FACTOR (lb/lb)	=	EMISSIONS (lb/yr)
CO	50		75		6.4		0.56		13,440
VOC	50		75		6.4		0.32		7,680
NO_x	50		75		6.4		0.0042		101
SO_x	50		75		6.4		-		-
PM	50		75		6.4		0.128		3,072

TABLE C-1 EMISSION FACTORS FOR LIVE FIRE TRAINING (JP-4)	
CO	0.56
VOC	0.32
NO_x	0.0042
SO_x	-*
PM	0.128

*Negligible.

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D. FUEL STORAGE EVAPORATIVE LOSSES

1. BACKGROUND

a. Fuel storage operations contribute exclusively to the generation of VOC emissions and typically involve jet fuels, gasoline, diesel, and various fuel oils. The compilation of VOC emission rates generated by these sources can be accomplished manually as explained within this section or by utilizing the most current version of EPA'S "TANKS" software program. This program and the directions for its downloading and use on personal computers are available on the EPA Bulletin Board. TANKS has a number of advantages over the manual method and we highly recommend its use.

b. VOC emissions are generated as a result of evaporative loss of the liquid during its storage and as a result of changes to the liquid level during filling and emptying operations. Emission rates and sources vary with tank design and condition. Tank designs used by Air Force installations include fixed roof, internal floating roof, and external floating roof (see figures D-8 through D-11 for illustrations).

(1) Fixed Roof Tanks: Standing storage emissions from these tanks are known as "breathing losses" and are expelled via vents during temperature and pressure-induced expansions and contractions. Evaporative losses produced during filling and emptying operations are known as "working losses." As the tank is filled, the vapor pressure within it exceeds the relief pressure and vapors are expelled from the tank. During fuel removal, air drawn into the tank to replace the liquid becomes saturated with organic vapor and expands, thereby exceeding the capacity of the vapor space. Fixed roof tanks are the least efficient of the three designs regarding VOC losses.

(2) External Floating Roof Tanks: Standing storage losses emanate from roof fittings and rim seals--which occupy the space between the edge of the floating roof and the tank wall. Some breathing losses also occur. Most of these losses are wind-induced. The other losses associated these tanks are called "withdrawal losses." During removal operations, fuel remains attached to the tank wall and evaporates as the fuel level, and thus the floating roof, is lowered.

(3) Internal Floating Roof Tanks: Standing storage losses from internal floating roof tanks include rim seal, deck fitting, and deck seam losses. Withdrawal losses are similar to those for external floating roof tanks with one major difference--wind is not a predominant factor affecting rim seal losses. Internal floating roof tanks are the most efficient of the three designs discussed here.

2. CALCULATIONS: Contact the Civil Engineering Squadron for physical data on storage tanks and Base Supply Fuels Management for data concerning petroleum liquids. Any other independent fuel storage facilities such as the Base Exchange Gas Station must also be considered.

a. **FIXED ROOF TANKS**: The following method applys to tanks with vertical cylindrical shells and fixed roofs. These tanks must be liquid-tight and vapor-tight and be operating under near-atmospheric pressure conditions.

(1) <u>Total Losses</u>: $L_T = L_S + L_W$ (A-1)

Where:

L_T = total losses (lb/yr)
L_S = standing storage losses (lb/yr)
L_W = working losses (lb/yr)

(2) <u>Standing Storage Losses</u>: $L_S = 365\ V_V W_V K_E K_S$ (A-2)

Where:

L_S = standing storage losses (lb/yr)
V_V = vapor space volume (ft^3), see Equation A-3
W_V = vapor density (lb/ft^3), see Equation A-10
K_E = vapor space expansion factor (dimensionless), see Equation A-14
K_S = vented vapor saturation factor (dimensionless), see Equation A-20
365 = days/yr (constant)

<u>Vapor Space Volume</u>: $V_V = (\pi/4)D^2 H_{VO}$ (A-3)

Where:

V_V = vapor space volume (ft^3)
D = tank diameter (ft); for horizontal tanks, see Equation A-9
H_{VO} = vapor space outage (ft)

The vapor space outage (H_{VO}) is the height of a cylinder of tank diameter D whose volume is equal to the vapor space volume of a fixed roof tank, including the volume under the cone or dome roof. H_{VO} is estimated for a cylindrical tank using Equation A-4:

Vapor Space Outage: $H_{VO} = H_S - H_L + H_{RO}$ (A-4)

Where:

H_{VO} = vapor space outage (ft)
H_S = tank shell height (ft)
H_L = liquid height (ft)
H_{RO} = roof outage (ft)

Roof outage for a Cone roof: $H_{RO} = 1/3 H_R$ (A-5)

Where:

H_{RO} = roof outage (ft)
H_R = tank roof height (ft)

Tank Roof Height: $H_R = S_R R_S$ (A-6)

Where:

S_R = tank cone roof slope (ft/ft), if unknown use 0.0625 ft/ft
R_S = tank shell radius (ft)

Roof outage for a **Dome** roof: $H_{RO} = H_R[1/2 + 1/6(H_R/R_S)^2]$ (A-7)
Where:

= roof outage (ft)
= tank roof height (ft)
R_S = tank shell radius (ft)

Tank Roof Height: $H_R = R_R - (R_R{}^2 - R_S{}^2)^{0.5}$ (A-8)

Where:

H_R = tank roof height (ft)
R_R = tank dome roof radius (ft)
R_S = tank shell radius (ft)

The value of R_R usually ranges from 0.8D to 1.2D. If R_R is unknown, the tank diameter is used in its place. If the tank diameter is used as the value for R_R, Equations A-7 and A-8 reduce to $H_R = 0.268R_S$ and $H_{RO} = 0.137R_S$.

Note: The emission estimating equations presented above were developed for vertical fixed roof tanks. To estimate emissions for a horizontal fixed roof tank, some of the tank parameters can be modified before using the vertical tank emission estimating equations. First, by assuming that the tank is one-half filled, the surface area of the liquid in the tank is approximately equal to the length of the tank times the diameter of the tank. Next, assume that this area represents a circle, i.e., that the liquid is an upright cylinder. Therefore, the effective tank diameter (D_E) can be estimated as:

Effective Tank Diameter: $D_E = \sqrt{LD/0.785}$ (A-9)

Where:

D_E = effective diameter (ft)
L = length of tank (ft)
D = actual diameter of tank (ft)

One half of the actual diameter of the horizontal tank should be used as the vapor space outage (H_{VO}). This method yields only a very approximate value for emissions from horizontal storage tanks. For underground horizontal tanks, assume that no standing storage losses occur ($L_S = 0$) because the insulating nature of the earth limits the diurnal temperature change. No modifications to the working loss equation are necessary for either above-ground or underground horizontal tanks.

<u>Vapor Density</u>: $W_V = M_V P_{VA}/RT_{LA}$ (A-10)

Where:

W_V = vapor density (lb/ft^3)
M_V = vapor molecular weight (lb/lb-mole), see Table D-1
P_{VA} = vapor pressure (psia) at daily average liquid surface temperature (T_{LA}), see Equation A-11 for T_{LA}, then use Table D-1 (°R - 460 = °F)
R = 10.731 psia-ft^3/lb-mole-°R (the ideal gas constant)
T_{LA} = daily average liquid surface temperature (°R); if the daily average liquid temperature (T_{LA}) is unknown, it is calculated using the following equation:

$$T_{LA} = 0.44T_{AA} + 0.56T_B + 0.0079\alpha I \quad \text{(A-11)}$$

Where:

T_{LA} = daily average liquid surface temperature (°R), °R = °F + 460
T_{AA} = daily average ambient temperature (°R), see Equation A-12
T_B = liquid bulk temperature (°R), see Equation A-13
α = tank paint solar absorptance (dimensionless), see Table D-2
I = daily total solar insolation factor (Btu/ft^2-day), see Table D-3

Daily Ambient Average Temperature: $T_{AA} = (T_{AX} + T_{AN})/2$ (A-12)

Where:

T_{AA} = daily average ambient temperature (°R)
T_{AX} = daily maximum ambient temperature (°R)
T_{AN} = daily minimum ambient temperature (°R)

Table D-3 gives values of T_{AX} and T_{AN} for selected U.S. cities. If available, use local data (°R).

Liquid Bulk Temperature: $T_B = T_{AA} + 6\alpha - 1$ (A-13)

Where:

T_B = liquid bulk temperature (°R)
T_{AA} = daily average ambient temperature (°R)
α = tank paint solar absorptance (dimensionless), see Table D-2

<u>Vapor Space Expand Factor</u>: $K_E = (\Delta T_V/T_{LA}) + [(\Delta P_V - \Delta P_B)/(P_A - P_{VA})]$ (A-14)

Where:

K_E = vapor space expansion factor
ΔT_V = daily vapor temperature range (°R), see Equation A-15
T_{LA} = daily average liquid surface temperature (°R), see Equation A-11

ΔP_V = daily vapor pressure range (psi), see Equation A-16
ΔP_B = breather vent pressure setting range (psi), see Equation A-19
P_A = 14.7 (constant, atmospheric pressure)
P_{VA} = vapor pressure (psia) at daily average liquid surface temperature (T_{LA}); see Equation A-10

Daily Vapor Temperature Range: $$\Delta T_V = 0.72\Delta T_A + 0.028\alpha I \quad \text{(A-15)}$$

Where:

ΔT_V = daily vapor temperature range (°R)
ΔT_A = daily ambient temperature range (°R) = T_{AX} - T_{AN} (see equa. A-12 for T_{AX} & T_{AN} definitions)
α = tank paint solar absorptance (dimensionless), see Table D-2
I = daily total solar isolation factor (Btu/ft^2-day); see Table D-3

Daily Vapor Pressure Range: $$\Delta P_V = P_{VX} - P_{VN} \quad \text{(A-16)}$$

ΔP_V = daily vapor pressure range (psia)
P_{VX} = vapor pressure (psia) at the daily maximum liquid surface temperature (T_{LX}); use Table D-1, extrapolate P_{VX} after converting T_{LX} to °F (Fig. D-12 can also be used for P_{VX})
P_{VN} = vapor pressure (psia) at the daily minimum liquid surface temperature (T_{LN}); use Table D-1, extrapolate P_{VN} after converting T_{LN} to °F (Fig. D-12 can also be used for P_{VN})

$$T_{LX} = T_{LA} + 0.25\Delta T_V \quad \text{(A-17)}$$

$$T_{LN} = T_{LA} - 0.25\Delta T_V \quad \text{(A-18)}$$

T_{LX} = daily maximum liquid surface temperature
T_{LN} = daily minimum liquid surface temperature
T_{LA} = daily average liquid surface temperature, see Equation A-11
ΔT_V = daily vapor temperature range (°R), see Equation A-15

Breather Vent Pressure Setting Range: $$\Delta P_B = P_{BP} - P_{BV} \quad \text{(A-19)}$$

Where:

ΔP_B = breather vent pressure setting range (psig)
P_{BP} = breather vent pressure setting (psig)
P_{BV} = breather vent vacuum setting (psig)

If specific information on the breather vent pressure setting and vacuum setting is not available, assume 0.03 psig for P_{BP} and -0.03 psig for P_{BV} as typical values. If the fixed roof tank is of bolted or riveted construction in which the roof or shell plates are not vapor tight, assume that $\Delta P_B = 0$, even if a breather vent is used. If the breather vent pressure or vacuum setting exceeds 1.0 psig, the standing storage losses could potentially be negative.

Vented Vapor Saturation Factor: $K_S = 1/(1 + 0.053P_{VA}H_{VO})$ (A-20)

Where:

K_S = vented vapor saturation factor (dimensionless)
P_{VA} = vapor pressure (psia) at daily average liquid surface temperature (see Equation A-10)
H_{VO} = vapor space outage (ft), see Equation A-4

(3) Working Losses: $L_W = 0.0010M_VP_{VA}QK_NK_P$ (A-21)

Where:

L_W = fixed-roof working losses (lb/yr)
M_V = molecular weight of vapor in storage tank (lb/lb-mole), see Table D-1
P_{VA} = true vapor pressure (psia) at daily average liquid surface temperature (see Equation A-10)
Q = annual net throughput [bbl/yr(tank capacity in bbl x # of turnovers per year)]
K_N = turnover factor (dimensionless);
for turnovers >36, $K_N = (180 + N)/6N$
for turnovers ≤ 36, $K_N = 1$
N = number of turnovers per year (dimensionless), see Equation A-22
K_P = working loss product factor (dimensionless); 0.75 for crude oils; for all other petroleum liquids, $K_P = 1$

Turnovers Per Year: $N = 5.614Q/V_{LX}$ (A-22)

Where:

N = number of turnovers per year (dimensionless)
Q = annual net throughput [bbl/yr(tank capacity in bbl x annual turnover rate)]
V_{LX} = tank maximum liquid volume (ft^3), see Equation A-23

Tank Maximum Liquid Volume: $V_{LX} = (\pi/4)D^2H_{LX}$ (A-23)

Where:

V_{LX} = tank maximum liquid value (ft^3)
D = tank diameter (ft)
H_{LX} = maximum liquid height (ft)

b. **INTERNAL FLOATING ROOF TANKS**: The following method applies only to freely vented internal floating roof tanks. These equations are not intended to estimate losses from closed internal floating roof tanks (tanks vented only through a pressure/vacuum vent).

(1) Total Losses: $L_T = L_R + L_{WD} + L_F + L_D$ (B-1)

Where:

L_T = total losses (lb/yr)
L_R = rim seal losses (see Equation B-2)
L_{WD} = withdrawl losses (see Equation B-4)
L_F = deck fitting losses (see Equation B-5)
L_D = deck seam losses (see Equation B-6)

(2) Rim Seal Losses: $L_R = K_R P^* D M_V K_C$ (B-2)

Where:

L_R = rim seal losses (lb/yr)
K_R = seal factor [lb-mole/(ft-yr)], see Table D-4
P^* = vapor pressure function (dimensionless), see Equation B-3 or use Figure D-1
D = tank diameter (ft)
M_V = average vapor molecular weight (lb/lb-mole), see Table D-1
K_C = product factor (dimensionless), for all petroleum liquids except crude oil, K_C = 1.0. For crude oil, K_C = 0.4.

Vapor Pressure Function: $P^* = (P_{VA}/P_A)/[1 + (1 - [P_{VA}/P_A])^{0.5}]^2$ (B-3)

Where:

P^* = vapor pressure function (dimensionless)
P_{VA} = vapor pressure (psia) at daily average liquid surface temperature (T_{LA}), see Equation A-10
P_A = 14.7 (constant, atmospheric pressure)

(3) Withdrawal Losses: $L_{WD} = [(0.943)QCW_L/D][1 + (N_C F_C/D)]$ (B-4)

Where:

L_{WD} = withdrawal losses (lb/yr)
Q = annual net throughput [bbl/yr(tank capacity in bbl x # of turnovers per year)]
C = shell clingage factor (bbl/1000ft^2), see Table D-5
W_L = average organic liquid density (lb/gal), see Table D-1
D = tank diameter (ft)
N_C = number of columns (dimensionless); for self-supporting fixed roof, NC = 0; for column supported roof, use tank-specific information or see Table D-6
F_C = effective column diameter (ft); use tank-specific effective column diameter or FC = 1.1 for 9-in. by 7-in built-up columns, 0.7 for 8-in-diameter pipe columns, and 1.0 if column construction details are not known
0.943 = constant (1000 ft^3 x gal/bbl^2)

$$L_F = F_F P^* M_V K_C \quad \text{(B-5)}$$

(4) Deck Fitting Losses: $L_F = F_F P^* M_V K_C$ (B-5)

Where:

L_F = deck fitting losses (lb/yr)
P^* = vapor pressure function (dimensionless), see Equation B-3 or use Figure D-1
M_V = average vapor molecular weight (lb/lb-mole), see Table D-1
K_C = product factor (dimensionless), see Equation B-2
F_F = deck fitting loss factor (lb-mole/yr)

$$F_F = [(N_{F1}K_{F1}) + (N_{F2}K_{F2}) + \ldots(N_{Fnf}K_{Fnf})] \quad \text{(B-6)}$$

Where:

N_{Fi} = number of deck fittings of a particular type (i = 0,1,2,...,n), dimensionless
K_{Fi} = deck fitting loss factor for a particular type fitting (i = 0,1,2...,n), lb-mole/yr
$_{nf}$ = total number of different types of fittings (dimensionless)

The value of F_F may be calculated using actual tank-specific data for the number of each fitting type (N_F) and then multiplying by the fitting loss factor for each fitting (K_F). Values of fitting loss factors and typical number of fittings are presented in Table D-7. Where tank-specific data for the number and kind of deck fittings are unavailable, F_F can be approximated for typical deck fittings in tanks according to tank diameter:

$F_F = (0.0132)D^2 + (0.79)D + 105.2$ (self-supporting fixed roofs and welded deck)
$F_F = (0.0228)D^2 + (0.79)D + 105.2$ (self-supporting fixed roofs and bolted deck)
$F_F = (0.0385)D^2 + (1.392)D + 134.2$ (column-supported fixed roofs and welded deck)
$F_F = (0.0481)D^2 + (1.392)D + 134.2$ (column-supported fixed roofs and bolted deck)

(5) Deck Seam Losses: $L_D = K_D S_D D^2 P^* M_V K_C$ (B-7)

Where:

L_D = deck seam losses
K_D = deck seam loss per unit seam length factor (lb-mole/ft-yr)
= 0.0 for welded deck and 0.34 for bolted deck
S_D = deck seam length factor (ft/ft^2)
= L_{seam}/A_{deck} Where:
L_{seam} = total length of deck seams (ft)
A_{deck} = area of deck (ft^2) = $\pi D^2/4$
D = tank diameter (ft)
P^* = vapor pressure function (dimensionless), see Equation B-3 or use Figure D-1
M_V = average vapor molecular weight (lb/lb-mole), see Table D-1
K_C = product factor (dimensionless), see Equation B-2

If the total length of the deck seam is not known, Table D-8 can be used to estimate S_D. Where tank-specific data concerning width of deck sheets or the size of deck panels is unavailable, a default value for S_D can be assigned. A value of 0.20 ft/ft^2 can be assumed to represent the most common bolted deck currently in use.

Note: Recently vendors of bolted decks have been using various techniques in an effort to reduce deck seam losses. However, emission factors are not currently available in AP-42 that represent the emission reduction achieved by these techniques. Some vendors have developed specific factors for their deck designs; however, use of these factors is not recommended until approval has been obtained from the governing regulatory agency or permitting authority.

c. **EXTERNAL FLOATING ROOF TANKS**: The following method is not intended for use in estimating losses from tanks in which the materials used in the rim seal and/or roof fitting are either deteriorated or significantly permeated by the stored liquid.

(1) Total Losses: $L_T = L_R + L_{WD} + L_F$ (C-1)

Where:

L_T = total losses (lb/yr)
L_R = rim seal losses (lb/yr), see Equation C-2
L_{WD} = withdrawal losses (lb/yr), see Equation C-3
L_F = roof fitting losses (lb/yr), see Equation C-4

(2) Rim Seal Losses: $L_R = K_R v^n P^* D M_V K_C$ (C-2)

Where:

L_R = Rim Seal Losses (lb/yr)
K_R = seal factor [lb-mole/(mph)^n-ft-yr], see Table D-9 or Note 2 below
v = average wind speed at tank site (mph), see Note 1 and Note 2
n = seal-related wind speed exponent (dimensionless), see Table D-9 or Note 2
P* = vapor pressure function (dimensionless), see Equation B-3 or use Figure D-1
D = tank diameter (ft)
M_V = average vapor molecular weight (lb/lb-mole), see Table D-1
K_C = product factor (dimensionless), see Equation B-2

Notes:

1. Use wind speed data furnished by the nearest local weather station or values from Table 10.

2. The rim seal loss factor, $F_R = K_R v^n$, can also be read directly from Figures D-2 through D-5. These figures present F_R for both average and tight fitting seals. However, it is recommended that only the values for average fitting seals be used in estimating rim seal losses because of difficulty in ensuring the seals are tight-fitting at all liquid heights in the tank.

(3) Withdrawal Losses: $L_{WD} = (0.943) QCW_L / D$ (C-3)

Where:

L_{WD} = withdrawal Losses (lb/yr)
Q = annual throughput [bbl/yr(tank capacity in bbl x # of turnovers per year)]
C = shell clingage factor (bbl/1000ft^2), see Table D-5
W_L = average petroleum liquid density (lb/gal), see Table D-1
D = tank diameter (ft)
0.943 = constant (1000 ft^3 x gal/bbl^2)

(4) <u>Roof Fitting Losses</u>: $L_F = F_F P^* M_V K_C$ (C-4)

Where:

L_F = roof fitting losses (lb/yr)
P^* = vapor pressure function (dimensionless), see Equation B-3 or use Figure 1
M_V = average vapor molecular weight (lb/lb-mole), see Table D-1
K_C = product factor (dimensionless), see Equation B-2
F_F = total roof fitting loss factor (lb-mole/yr)

$$F_F = [(N_{F1}K_{F1}) + (N_{F2}K_{F2}) + \ldots(N_{Fnf}K_{Fnf})] \tag{C-5}$$

Where:

N_{Fi} = number of roof fittings of a particular type (i = 0,1,2,...,n), dimensionless
N_{Fi} = roof fitting loss factor for a particular type fitting (i = 0,1,2...,n), lb-mole/yr
$_{nf}$ = total number of different types of fittings (dimensionless)

The value of F_F may be calculated using actual tank-specific data for the number of each fitting type (N_F) and then multiplying by the fitting loss factor for each fitting (K_F). Values for typical number of roof fittings (N_F) are presented in Tables D-11 through D-13. The roof fitting loss factor (K_{Fi}) for a particular type of fitting can be estimated by using the following equation in conjunction with Table D-11. (Table D-11 applies only when the average wind speed falls between 2 and 15 miles per hour)

$$K_{Fi} = K_{Fai} + K_{Fbi}v^{mi} \tag{C-6}$$

Where:

K_{Fi} = loss factor for a particular type of roof fitting (lb-moles/yr)
K_{Fai} = loss factor for a particular type of roof fitting (lb-moles/yr)
K_{Fbi} = loss factor for a particular type of roof fitting [lb-mole/(mph)^m-yr]
m_i = loss factor for a particular type of roof fitting (dimensionless)
v = average wind speed (mph)
i = 1,2,...,n (dimensionless)

Where tank-specific data for the number and kind of deck fittings are unavailable, F_F can be approximated according to tank diameter using Figures D-6 and D-7 for pontoon and double-deck external floating roofs, respectively.

BIBLIOGRAPHY

(U.S.) Environmental Protection Agency. <u>Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources (AP-42), 4th Ed., Sup. A-E</u>. Research Triangle Park NC, October 1992.

TABLE D-1 PHYSICAL PROPERTIES OF TYPICAL ORGANIC LIQUIDS*										
Petroleum Liquids	Vapor Molecular Weight @ 60°F	Product Density (d) lb/gal @ 60°F	Condensed Vapor Density (w) lb/gal @ 60°F	True Vapor Pressure in psia at:						
				40°F	50°F	60°F	70°F	80°F	90°F	100°F
Gasoline RVP 13	62	5.6	4.9	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gasoline RVP 10	66	5.6	5.1	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gasoline RVP 7	68	5.6	5.2	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Crude Oil RVP 5	50	7.1	4.5	1.8	2.3	2.8	3.4	4.0	4.8	5.7
Jet Naphtha (JP-4)	80	6.4	5.4	0.8	1.0	1.3	1.6	1.9	2.4	2.7
Distillate Fuel #2	130	7.1	6.1	0.0031	0.0045	0.0074	0.0090	0.012	0.016	0.022
Residual Oil #6	190	7.9	6.4	0.00002	0.00003	0.00004	0.00006	0.00009	0.00013	0.0002

* See Appendix B for JP-8 properties.

TABLE D-2 PAINT SOLAR ABSORPTANCE*			
		Paint Factors (α)	
		Paint Condition	
Paint Color	Paint Shade or Type	Good	Poor
Aluminum	Specular	0.39	0.49
Aluminum	Diffuse	0.60	0.68
Gray	Light	0.54	0.63
Gray	Medium	0.68	0.74
Red	Primer	0.89	0.91
White	---	0.17	0.34

*If the tank roof and shell are different colors, α is determined from $\alpha = (\alpha_R + \alpha_s)/2$; where α_R is the tank roof paint solar absorptance and α_s is the tank shell paint solar absorptance.

TABLE D-3
METEOROLOGICAL DATA (T_{AX}, T_{AN}, I) FOR SELECTED U.S. LOCATIONS

Location	Property: Symbol	Property: Units	Monthly averages: Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual average
Birmingham, AL	T_{AX}	°F	52.7	57.3	65.2	75.2	81.6	87.9	90.3	89.7	84.6	74.8	63.7	55.9	73.2
	T_{AN}	°F	33.0	35.2	42.1	50.4	58.3	65.9	69.8	69.1	63.6	50.4	40.5	35.2	51.1
	I	Btu/ft² day	707	967	1296	1674	1857	1919	1810	1724	1455	1211	858	661	1345
Montgomery, AL	T_{AX}	°F	57.0	60.9	68.1	77.0	83.6	89.8	91.5	91.2	86.9	77.5	67.0	59.8	75.9
	T_{AN}	°F	36.4	38.8	45.5	53.3	61.1	68.4	71.8	71.1	66.4	53.1	43.0	37.9	53.9
	I	Btu/ft² day	752	1013	1341	1729	1897	1972	1841	1746	1468	1262	915	719	1388
Homer, AK	T_{AX}	°F	27.0	31.2	34.4	42.1	49.8	56.3	60.5	60.3	54.8	44.0	34.9	27.7	43.6
	T_{AN}	°F	14.4	17.4	19.3	28.1	34.6	41.2	45.1	45.2	39.7	30.6	22.8	15.8	29.5
	I	Btu/ft² day	122	334	759	1248	1583	1751	1598	1189	791	437	175	64	838
Phoenix, AZ	T_{AX}	°F	65.2	69.7	74.5	83.1	92.4	102.3	105.0	102.3	98.2	87.7	74.3	66.4	85.1
	T_{AN}	°F	39.4	42.5	46.7	53.0	61.5	70.6	79.5	77.5	70.9	59.1	46.9	40.2	57.3
	I	Btu/ft² day	1021	1374	1814	2355	2677	2739	2487	2293	2015	1577	1151	932	1869
Tucson, AZ	T_{AX}	°F	64.1	67.4	71.8	80.1	88.8	98.5	98.5	95.9	93.5	84.1	72.2	65.0	81.7
	T_{AN}	°F	38.1	40.0	43.8	49.7	57.5	67.4	73.8	72.0	67.3	56.7	45.2	39.0	54.2
	I	Btu/ft² day	1099	1432	1864	2363	2671	2730	2341	2183	1979	1602	1208	996	1872
Fort Smith, AR	T_{AX}	°F	48.4	53.8	62.5	73.7	81.0	88.5	93.6	92.9	85.7	75.9	61.9	52.1	72.5
	T_{AN}	°F	26.6	30.9	38.5	49.1	58.2	66.3	70.5	68.9	62.1	49.0	37.7	30.2	49.0
	I	Btu/ft² day	744	999	1312	1616	1912	2089	2065	1877	1502	1201	851	682	1404
Little Rock, AR	T_{AX}	°F	49.8	54.5	63.2	73.8	81.7	89.5	92.7	92.3	85.6	75.8	62.4	53.2	72.9
	T_{AN}	°F	29.9	33.6	41.2	50.9	59.2	67.5	71.4	69.6	63.0	50.4	40.0	33.2	50.8
	I	Btu/ft² day	731	1003	1313	1611	1929	2107	2032	1861	1518	1228	847	674	1404
Bakersfield, CA	T_{AX}	°F	57.4	63.7	68.6	75.1	83.9	92.2	98.8	96.4	90.8	81.0	67.4	57.6	77.7
	T_{AN}	°F	38.9	42.6	45.5	50.1	57.2	64.3	70.1	68.5	63.8	54.9	44.9	38.7	53.3
	I	Btu/ft² day	766	1102	1595	2095	2509	2749	2684	2421	1992	1458	942	677	1749
Long Beach, CA	T_{AX}	°F	66.0	67.3	68.0	70.9	73.4	77.4	83.0	83.8	82.5	78.4	72.7	67.4	74.2
	T_{AN}	°F	44.3	45.9	47.7	50.8	55.2	58.9	62.6	64.0	61.6	56.6	49.6	44.7	53.5
	I	Btu/ft² day	928	1215	1610	1938	2065	2140	2300	2100	1701	1326	1004	847	1598
Los Angeles AP, CA	T_{AX}	°F	64.6	65.5	65.1	66.7	69.1	72.0	75.3	76.5	76.4	74.0	70.3	66.1	70.1
	T_{AN}	°F	47.3	48.6	49.7	52.2	55.7	59.1	62.6	64.0	62.5	58.5	52.1	47.8	55.0
	I	Btu/ft² day	926	1214	1619	1951	2060	2119	2308	2080	1681	1317	1004	849	1594
Sacramento, CA	T_{AX}	°F	52.6	59.4	64.1	71.0	79.7	87.4	93.3	91.7	87.6	77.7	63.2	53.2	73.4
	T_{AN}	°F	37.9	41.2	42.4	45.3	50.1	55.1	57.9	57.6	55.8	50.0	42.8	37.9	47.8
	I	Btu/ft² day	597	939	1458	2004	2435	2684	2688	2368	1907	1315	782	538	1643
San Francisco AP, CA	T_{AX}	°F	55.5	59.0	60.6	63.0	66.3	69.6	71.0	71.8	73.4	70.0	62.7	56.3	64.9
	T_{AN}	°F	41.5	44.1	44.9	46.6	49.3	52.0	53.3	54.2	54.3	51.2	46.3	42.2	48.3
	I	Btu/ft² day	708	1009	1455	1920	2226	2377	2392	2117	1742	1226	821	642	1608

TABLE D-3 (Continued)

Location	Property		Monthly averages												Annual average
	Symbol	Units	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Santa Maria, CA	T_{AX}	°F	62.8	64.2	63.9	65.6	67.3	69.9	72.1	72.8	74.2	73.3	68.9	64.6	68.3
	T_{AN}	°F	38.8	40.3	40.9	42.7	46.2	49.6	52.4	53.2	51.8	47.6	42.1	38.3	45.3
	I	Btu/ft² day	854	1141	1582	1921	2141	2349	2341	2106	1730	1353	974	804	1608
Denver, CO	T_{AX}	°F	43.1	46.9	51.2	61.0	70.7	81.6	88.0	85.8	77.5	66.8	52.4	46.1	64.3
	T_{AN}	°F	15.9	20.2	24.7	33.7	43.6	52.4	58.7	57.0	47.7	36.9	25.1	18.9	36.2
	I	Btu/ft² day	840	1127	1530	1879	2135	2351	2273	2044	1727	1301	884	732	1568
Grand Junction, CO	T_{AX}	°F	35.7	44.5	54.1	65.2	76.2	87.9	94.0	90.3	81.9	68.7	51.0	38.7	65.7
	T_{AN}	°F	15.2	22.4	29.7	38.2	48.0	56.6	63.8	61.5	52.2	41.1	28.2	17.9	39.6
	I	Btu/ft² day	791	1119	1554	1986	2380	2599	2465	2182	1834	1345	918	731	1659
Wilmington, DE	T_{AX}	°F	39.2	41.8	50.9	63.0	72.7	81.2	85.6	84.1	77.8	66.7	54.8	43.6	63.5
	T_{AN}	°F	23.2	24.6	32.6	41.8	51.7	61.2	66.3	65.4	58.0	45.9	36.4	27.3	44.5
	I	Btu/ft² day	571	827	1149	1480	1710	1883	1823	1615	1318	984	645	489	1208
Atlanta, GA	T_{AX}	°F	51.2	55.3	63.2	73.2	79.8	85.6	87.9	87.6	82.3	72.9	62.6	54.1	71.3
	T_{AN}	°F	32.6	34.5	41.7	50.4	58.7	65.9	69.2	68.7	63.6	51.4	41.3	34.8	51.1
	I	Btu/ft² day	718	969	1304	1686	1854	1914	1812	1709	1422	1200	883	674	1345
Savannah, GA	T_{AX}	°F	60.3	63.1	69.9	77.8	84.2	88.6	90.8	90.1	85.6	77.8	69.5	62.5	76.7
	T_{AN}	°F	37.9	40.0	46.8	54.1	62.3	68.5	71.5	71.4	67.6	55.9	45.5	39.4	55.1
	I	Btu/ft² day	795	1044	1399	1761	1852	1844	1784	1621	1364	1217	941	754	1365
Honolulu, HI	T_{AX}	°F	79.9	80.4	81.4	82.7	84.8	86.2	87.1	88.3	88.2	86.7	83.9	81.4	84.2
	T_{AN}	°F	65.3	65.3	67.3	68.7	70.2	71.9	73.1	73.6	72.9	72.2	69.2	66.5	69.7
	I	Btu/ft² day	1180	1396	1622	1796	1949	2004	2002	1967	1810	1540	1266	1133	1639
Chicago, IL	T_{AX}	°F	29.2	33.9	44.3	58.8	70.0	79.4	83.3	82.1	75.5	64.1	48.2	35.0	58.7
	T_{AN}	°F	13.6	18.1	27.6	38.8	48.1	57.7	62.7	61.7	53.9	42.9	31.4	20.3	39.7
	I	Btu/ft² day	507	760	1107	1459	1789	2007	1944	1719	1354	969	566	402	1215
Springfield, IL	T_{AX}	°F	32.8	38.0	48.9	64.0	74.6	84.1	87.1	84.7	79.3	67.5	51.2	38.4	62.6
	T_{AN}	°F	16.3	20.9	30.3	42.6	52.5	62.0	65.9	63.7	55.8	44.4	32.9	23.0	42.5
	I	Btu/ft² day	585	861	1143	1515	1866	2097	2058	1806	1454	1068	677	490	1302
Indianapolis, IN	T_{AX}	°F	34.2	38.5	49.3	63.1	73.4	82.3	85.2	83.7	77.9	66.1	50.8	39.2	62.0
	T_{AN}	°F	17.8	21.1	30.7	41.7	51.5	60.9	64.9	62.7	55.3	43.4	32.8	23.7	42.2
	I	Btu/ft² day	496	747	1037	1398	1638	1868	1806	1644	1324	977	579	417	1165
Wichita, KS	T_{AX}	°F	39.8	46.1	55.8	68.1	77.1	87.4	92.9	91.5	82.0	71.2	55.1	44.6	67.6
	T_{AN}	°F	19.4	24.1	32.4	44.5	54.6	64.7	69.8	67.9	59.2	46.9	33.5	24.2	45.1
	I	Btu/ft² day	784	1058	1406	1783	2036	2264	2239	2032	1616	1250	871	690	1502

TABLE D-3 (Continued)

Location	Property: Symbol	Property: Units	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual average
Louisville, KY	T_{AX}	°F	40.8	45.0	54.9	67.5	76.2	84.0	87.6	86.7	80.6	69.2	55.5	45.4	66.1
	T_{AN}	°F	24.1	26.8	35.2	45.6	54.6	63.3	67.5	66.1	59.1	46.2	36.6	28.9	46.2
	I	Btu/ft^2 day	546	789	1102	1467	1720	1904	1838	1680	1361	1042	653	488	1216
Baton Rouge, LA	T_{AX}	°F	61.1	64.5	71.6	79.2	85.2	90.6	91.4	90.8	87.4	80.1	70.1	63.8	78.0
	T_{AN}	°F	40.5	42.7	49.4	57.5	64.3	70.0	72.8	72.0	68.3	56.3	47.2	42.3	57.0
	I	Btu/ft^2 day	785	1054	1379	1681	1871	1926	1746	1677	1464	1301	920	737	1379
Lake Charles, LA	T_{AX}	°F	60.8	64.0	70.5	77.8	84.1	89.4	91.0	90.8	87.5	80.8	70.5	64.0	77.6
	T_{AN}	°F	42.2	44.5	50.8	58.9	65.6	71.4	73.5	72.8	68.9	57.7	48.9	43.8	58.3
	I	Btu/ft^2 day	728	1010	1313	1570	1849	1970	1788	1657	1485	1381	917	706	1365
New Orleans, LA	T_{AX}	°F	61.8	64.6	71.2	78.6	84.5	89.5	90.7	90.2	86.8	79.4	70.1	64.4	77.7
	T_{AN}	°F	43.0	44.8	51.6	58.8	65.3	70.9	73.5	73.1	70.1	59.0	49.9	44.8	58.7
	I	Btu/ft^2 day	835	1112	1415	1780	1968	2004	1814	1717	1514	1335	973	779	1437
Detroit, MI	T_{AX}	°F	30.6	33.5	43.4	57.7	69.4	79.0	83.1	81.5	74.4	62.5	47.6	35.4	58.2
	T_{AN}	°F	16.1	18.0	26.5	36.9	46.7	56.3	60.7	59.4	52.2	41.2	31.4	21.6	38.9
	I	Btu/ft^2 day	417	680	1000	1399	1716	1866	1835	1576	1253	876	478	344	1120
Grand Rapids, MI	T_{AX}	°F	29.0	31.7	41.6	56.9	69.4	78.9	83.0	81.1	73.4	61.4	46.0	33.8	57.2
	T_{AN}	°F	14.9	15.6	24.5	35.6	45.5	55.3	59.8	58.1	50.8	40.4	30.9	20.7	37.7
	I	Btu/ft^2 day	370	648	1014	1412	1755	1957	1914	1676	1262	858	446	311	1135
Minneapolis-St. Paul, MN	T_{AX}	°F	19.9	26.4	37.5	56.0	69.4	78.5	83.4	80.9	71.0	59.7	41.1	26.7	54.2
	T_{AN}	°F	2.4	8.5	20.8	36.0	47.6	57.7	62.7	60.3	50.2	39.4	25.3	11.7	35.2
	I	Btu/ft^2 day	464	764	1104	1442	1737	1928	1970	1687	1255	860	480	353	1170
Jackson, MS	T_{AX}	°F	56.5	60.9	68.4	77.3	84.1	90.5	92.5	92.1	87.6	78.6	67.5	60.0	76.3
	T_{AN}	°F	34.9	37.2	44.2	52.9	60.8	67.9	71.3	70.2	65.1	51.4	42.3	37.1	52.9
	I	Btu/ft^2 day	754	1026	1369	1708	1941	2024	1909	1781	1509	1271	902	709	1409
Billings, MT	T_{AX}	°F	29.9	37.9	44.0	55.9	66.4	76.3	86.6	84.3	72.3	61.0	44.4	36.0	57.9
	T_{AN}	°F	11.8	18.8	23.6	33.2	43.3	51.6	58.0	56.2	46.5	37.5	25.5	18.2	35.4
	I	Btu/ft^2 day	486	763	1190	1526	1913	2174	2384	2022	1470	987	561	421	1325
Las Vegas, NV	T_{AX}	°F	56.0	62.4	68.3	77.2	87.4	98.6	104.5	101.9	94.7	81.5	66.0	57.1	79.6
	T_{AN}	°F	33.0	37.7	42.3	49.8	59.0	68.6	75.9	73.9	65.6	53.5	41.2	33.6	52.8
	I	Btu/ft^2 day	978	1340	1824	2319	2646	2778	2588	2355	2037	1540	1086	881	1864
Newark, NJ	T_{AX}	°F	38.2	40.3	49.1	61.3	71.6	80.6	85.6	84.0	76.9	66.0	54.0	42.3	62.5
	T_{AN}	°F	24.2	25.3	33.3	42.9	53.0	62.4	67.9	67.0	59.4	48.3	39.0	28.6	45.9
	I	Btu/ft^2 day	552	793	1109	1449	1687	1795	1760	1565	1273	951	596	454	1165

Month columns Jan.–Dec. are under the spanning head "Monthly averages".

TABLE D-3 (Continued)

Location	Symbol	Units	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual average
Roswell, NM	T_{AX}	°F	55.4	60.4	67.7	76.9	85.0	93.1	93.7	91.3	84.9	75.8	63.1	56.7	75.3
	T_{AN}	°F	27.4	31.4	37.9	46.8	55.6	64.8	69.0	67.0	59.6	47.5	35.0	28.2	47.5
	I	Btu/ft² day	1047	1373	1807	2218	2459	2610	2441	2242	1913	1527	1131	952	1810
Buffalo, NY	T_{AX}	°F	30.0	31.4	40.4	54.4	65.9	75.6	80.2	78.2	71.4	60.2	47.0	35.0	55.8
	T_{AN}	°F	17.0	17.5	25.6	36.3	46.3	56.4	61.2	59.6	52.7	42.7	33.6	22.5	39.3
	I	Btu/ft² day	349	546	889	1315	1597	1804	1776	1513	1152	784	403	283	1034
New York, NY (LaGuardia Airport)	T_{AX}	°F	37.4	39.2	47.3	59.6	69.7	78.7	83.9	82.3	75.2	64.5	52.9	41.5	61.0
	T_{AN}	°F	26.1	27.3	34.6	44.2	53.7	63.2	68.9	68.2	61.2	50.5	41.2	30.8	47.5
	I	Btu/ft² day	548	795	1118	1457	1690	1802	1784	1583	1280	951	593	457	1171
Cleveland, OH	T_{AX}	°F	32.5	34.8	44.8	57.9	68.5	78.0	81.7	80.3	74.2	62.7	49.3	37.5	58.5
	T_{AN}	°F	18.5	19.9	28.4	38.3	47.9	57.2	61.4	60.5	54.0	43.6	34.3	24.6	40.7
	I	Btu/ft² day	388	601	922	1350	1681	1843	1828	1583	1240	867	466	318	1091
Columbus, OH	T_{AX}	°F	34.7	38.1	49.3	62.3	72.6	81.3	84.4	83.0	76.9	65.0	50.7	39.4	61.5
	T_{AN}	°F	19.4	21.5	30.6	40.5	50.2	59.0	63.2	61.7	54.6	42.8	33.5	24.7	41.8
	I	Btu/ft² day	459	677	980	1353	1647	1813	1755	1641	1282	945	538	387	1123
Toledo, OH	T_{AX}	°F	30.7	34.0	44.6	59.1	70.5	79.9	83.4	81.8	75.1	63.3	47.9	35.5	58.8
	T_{AN}	°F	15.5	17.5	26.1	36.5	46.6	56.0	60.2	58.4	51.2	40.1	30.6	20.6	38.3
	I	Btu/ft² day	435	680	997	1384	1717	1878	1849	1616	1276	911	498	355	1133
Oklahoma City, OK	T_{AX}	°F	46.6	52.2	61.0	71.7	79.0	87.6	93.5	92.8	84.7	74.3	59.9	50.7	71.2
	T_{AN}	°F	25.2	29.4	37.1	48.6	57.7	66.3	70.6	69.4	61.9	50.2	37.6	29.1	48.6
	I	Btu/ft² day	801	1055	1400	1725	1918	2144	2128	1950	1554	1233	901	725	1461
Tulsa, OK	T_{AX}	°F	45.6	51.9	60.8	72.4	79.7	87.9	93.9	93.0	85.0	74.9	60.2	50.3	71.3
	T_{AN}	°F	24.8	29.5	37.7	49.5	58.5	67.5	72.4	70.3	62.5	50.3	38.1	29.3	49.2
	I	Btu/ft² day	732	978	1306	1603	1822	2021	2031	1865	1473	1164	827	659	1373
Astoria, OR	T_{AX}	°F	46.8	50.6	51.9	55.5	60.2	63.9	67.9	68.6	67.8	61.4	53.5	48.8	58.1
	T_{AN}	°F	35.4	37.1	36.9	39.7	44.1	49.2	52.2	52.6	49.2	44.3	39.7	37.3	43.1
	I	Btu/ft² day	315	545	866	1253	1608	1626	1746	1499	1183	713	387	261	1000
Portland, OR	T_{AX}	°F	44.3	50.4	54.5	60.2	66.9	72.7	79.5	78.6	74.2	63.9	52.3	46.4	62.0
	T_{AN}	°F	33.5	36.0	37.4	40.6	46.4	52.2	55.8	55.8	51.1	44.6	38.6	35.4	44.0
	I	Btu/ft² day	310	554	895	1308	1663	1773	2037	1674	1217	724	388	260	1067
Philadelphia, PA	T_{AX}	°F	38.6	41.1	50.5	63.2	73.0	81.7	86.1	84.6	77.8	66.5	54.5	43.0	63.4
	T_{AN}	°F	23.8	25.0	33.1	42.6	52.5	61.5	66.8	66.0	58.6	46.5	37.1	28.0	45.1
	I	Btu/ft² day	555	795	1108	1434	1660	1811	1758	1575	1281	959	619	470	1169

TABLE D-3 (Continued)

Location	Property		Monthly averages												Annual average
	Symbol	Units	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Pittsburgh, PA	T_{AX}	°F	34.1	36.8	47.6	60.7	70.8	79.1	82.7	81.1	74.8	62.9	49.8	38.4	59.9
	T_{AN}	°F	19.2	20.7	29.4	39.4	48.5	57.1	61.3	60.1	53.3	42.1	33.3	24.3	40.7
	I	Btu/ft^2 day	424	625	943	1317	1602	1762	1689	1510	1209	895	505	347	1069
Providence, RI	T_{AX}	°F	36.4	37.7	45.5	57.5	67.6	76.6	81.7	80.3	73.1	63.2	51.9	40.5	59.3
	T_{AN}	°F	20.0	20.9	29.2	38.3	47.6	57.0	63.3	61.9	53.8	43.1	34.8	24.1	41.2
	I	Btu/ft^2 day	506	739	1032	1374	1655	1776	1695	1499	1209	907	538	419	1112
Columbia, SC	T_{AX}	°F	56.2	59.5	67.1	77.0	83.8	89.2	91.9	91.0	85.5	76.5	67.1	58.8	75.3
	T_{AN}	°F	33.2	34.6	41.9	50.5	59.1	66.1	70.1	69.4	63.9	50.3	40.6	34.7	51.2
	I	Btu/ft^2 day	762	1021	1355	1747	1895	1947	1842	1703	1439	1211	921	722	1380
Sioux Falls, SD	T_{AX}	°F	22.9	29.3	40.1	58.1	70.5	80.3	86.2	83.9	73.5	62.1	43.7	29.3	56.7
	T_{AN}	°F	1.9	8.9	20.6	34.6	45.7	56.3	61.8	59.7	48.5	36.7	22.3	10.1	33.9
	I	Btu/ft^2 day	533	802	1152	1543	1894	2100	2150	1845	1410	1005	608	441	1290
Memphis, TN	T_{AX}	°F	48.3	53.0	61.4	72.9	81.0	88.4	91.5	90.3	84.3	74.5	61.4	52.3	71.6
	T_{AN}	°F	30.9	34.1	41.9	52.2	60.9	68.9	72.6	70.8	64.1	51.3	41.1	34.3	51.9
	I	Btu/ft^2 day	683	945	1278	1639	1885	2045	1972	1824	1471	1205	817	629	1366
Amarillo, TX	T_{AX}	°F	49.1	53.1	60.8	71.0	79.1	88.2	91.4	89.6	82.4	72.7	58.7	51.8	70.7
	T_{AN}	°F	21.7	26.1	32.0	42.0	51.9	61.5	66.2	64.5	56.9	45.5	32.1	24.8	43.8
	I	Btu/ft^2 day	960	1244	1631	2019	2212	2393	2281	2103	1761	1404	1033	872	1659
Corpus Christi, TX	T_{AX}	°F	66.5	69.9	76.1	82.1	86.7	91.2	94.2	94.1	90.1	83.9	75.1	69.3	81.6
	T_{AN}	°F	46.1	48.7	55.7	63.9	69.5	74.1	75.6	75.8	72.8	64.1	54.9	48.8	62.5
	I	Btu/ft^2 day	898	1147	1430	1642	1866	2094	2186	1991	1687	1416	1043	845	1521
Dallas, TX	T_{AX}	°F	54.0	59.1	67.2	76.8	84.4	93.2	97.8	97.3	89.7	79.5	66.2	58.1	76.9
	T_{AN}	°F	33.9	37.8	44.9	55.0	62.9	70.8	74.7	73.7	67.5	56.3	44.9	37.4	55.0
	I	Btu/ft^2 day	822	1071	1422	1627	1889	2135	2122	1950	1587	1276	936	780	1468
Houston, TX	T_{AX}	°F	61.9	65.7	72.1	79.0	85.1	90.9	93.6	93.1	88.7	81.9	71.6	65.2	79.1
	T_{AN}	°F	40.8	43.2	49.8	58.3	64.7	70.2	72.5	72.1	68.1	57.5	48.6	42.7	57.4
	I	Btu/ft^2 day	772	1034	1297	1522	1775	1898	1828	1686	1471	1276	924	730	1351
Midland-Odessa, TX	T_{AX}	°F	57.6	62.1	69.8	78.8	86.0	93.0	94.2	93.1	86.4	77.7	65.5	59.7	77.0
	T_{AN}	°F	29.7	33.3	40.2	49.4	58.2	66.6	69.2	68.0	61.9	51.1	39.0	32.2	49.9
	I	Btu/ft^2 day	1081	1383	1839	2192	2430	2562	2389	2210	1844	1522	1176	1000	1802
Salt Lake City, UT	T_{AX}	°F	37.4	43.7	51.5	61.1	72.4	83.3	93.2	90.0	80.0	66.7	50.2	38.9	64.0
	T_{AN}	°F	19.7	24.4	29.9	37.2	45.2	53.3	61.8	59.7	50.0	39.3	29.2	21.6	39.3
	I	Btu/ft^2 day	639	989	1454	1894	2362	2561	2590	2254	1843	1293	788	570	1603

TABLE D-3 (Continued)

Location	Property		Monthly averages												Annual average
	Symbol	Units	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Richmond, VA	T_{AX}	°F	46.7	49.6	58.5	70.6	77.9	84.8	88.4	87.1	81.0	70.5	60.5	50.2	68.8
	T_{AN}	°F	26.5	28.1	35.8	45.1	54.2	62.2	67.2	66.4	59.3	46.7	37.3	29.6	46.5
	I	Btu/ft^2 day	632	877	1210	1566	1762	1872	1774	1601	1348	1033	733	567	1248
Seattle, WA (Sea-Tac Airport)	T_{AX}	°F	43.9	48.8	51.1	56.8	64.0	69.2	75.2	73.9	68.7	59.5	50.3	45.6	58.9
	T_{AN}	°F	34.3	36.8	37.2	40.5	46.0	51.1	54.3	54.3	51.2	45.3	39.3	36.3	43.9
	I	Btu/ft^2 day	262	495	849	1294	1714	1802	2248	1616	1148	656	337	211	1053
Charleston, WV	T_{AX}	°F	41.8	45.4	55.4	67.3	76.0	82.5	85.2	84.2	78.7	67.7	55.6	45.9	65.5
	T_{AN}	°F	23.9	25.8	34.1	43.3	51.8	59.4	63.8	63.1	56.4	44.0	35.0	27.8	44.0
	I	Btu/ft^2 day	498	707	1010	1356	1639	1776	1683	1514	1272	972	613	440	1123
Huntington, WV	T_{AX}	°F	41.1	45.0	55.2	67.2	75.7	82.6	85.6	84.4	78.7	67.6	55.2	45.2	65.3
	T_{AN}	°F	24.5	26.6	35.0	44.4	52.8	60.7	65.1	64.0	57.2	44.9	35.9	28.5	45.0
	I	Btu/ft^2 day	526	757	1067	1448	1710	1844	1769	1580	1306	1004	638	467	1176
Cheyenne, WY	T_{AX}	°F	37.3	40.7	43.6	54.0	64.6	75.4	83.1	80.8	72.1	61.0	46.5	40.4	58.3
	T_{AN}	°F	14.8	17.9	20.6	29.6	39.7	48.5	54.6	52.8	43.7	34.0	23.1	18.2	33.1
	I	Btu/ft^2 day	766	1068	1433	1771	1995	2258	2230	1966	1667	1242	823	671	1491

TABLE D-4 INTERNAL FLOATING ROOF RIM SEAL LOSS FACTORS	
Rim Seal System Description	K_R (lb-mole/ft-yr) Average
Vapor-mounted Primary Seal Only	6.7*
Liquid-mounted Primary Seal Only	3.0
Vapor-mounted Primary Seal Plus Secondary Seal	2.5
Liquid-mounted Primary Seal Plus Secondary Seal	1.6

*If no specific information is available, this value can be assumed to represent the most common/typical rim seal system in use.

TABLE D-5 AVERAGE CLINGAGE FACTORS (Barrels per 1000 ft^2)			
	Shell Condition		
Product Stored	Light Rust	Dense Rust	Gunite Lining
Gasoline	0.0015	0.0075	0.15
Single-component Stocks	0.0015	0.0075	0.15
Crude Oil	0.0060	0.030	0.60

TABLE D-6 TYPICAL NUMBER OF COLUMNS AS A FUNCTION OF TANK DIAMETER[a,b]	
Tank Diameter Range in Feet (D)	Typical Number of Columns (N_C)
$0 < D \leq 85$	1
$85 < D \leq 100$	6
$100 < D \leq 120$	7
$120 < D \leq 135$	8
$135 < D \leq 150$	9
$150 < D \leq 170$	16
$170 < D \leq 190$	19
$190 < D \leq 220$	22
$220 < D \leq 235$	31
$235 < D \leq 270$	37
$270 < D \leq 275$	43
$275 < D \leq 290$	49
$290 < D \leq 330$	61
$330 < D \leq 360$	71
$360 < D \leq 400$	81

[a]For Internal Floating Roof Tanks with column-supported fixed roofs.
[b]This table was derived from a survey of users and manufacturers. The actual number of columns in a particular tank may vary greatly with age, fixed roof style, loading specifications, and manufacturing prerogatives. Data on this table should not supersede information on actual tanks.

TABLE D-7
SUMMARY OF INTERNAL FLOATING DECK FITTING LOSS FACTORS (K_F)
AND TYPICAL NUMBER OF FITTINGS (N_F)

Deck Fitting Type	Deck Fitting Loss Factor (K_F), lb-mole/yr	Typical Number of Fittings (N_F)
Access Hatch (24-inch diameter)		
Bolted Cover, Gasketed	1.6	1
Unbolted Cover, Gasketed	11	
Unbolted Cover, Ungasketed	25[a]	
Automatic Guage Float Well		
Bolted Cover, Gasketed	5.1	1
Unbolted Cover, Gasketed	15	
Unbolted Cover, Ungasketed	28[a]	
Column Well (24-inch diameter)[b]		
Builtup Column-sliding Cover, Gasketed	33	
Builtup Column-sliding Cover, Ungasketed	47[a]	see Table D-6
Pipe Column-flexible Fabric Sleeve Seal	10	
Pipe Column-sliding Cover, Gasketed	19	
Pipe Column-sliding Cover, Ungasketed	32	
Ladder Well (36-inch diameter)[b]		
Sliding Cover, Gasketed	56	1[c]
Sliding Cover, Ungasketed	76[a]	
Roof Leg or Hangar Well		
Adjustable	7.9[a]	$[5+(D/10)+(D^2/600)]$
Fixed	0	
Sample Pipe or Well (24-inch diameter)		
Slotted Pipe-sliding Cover, Gasketed	44	1
Slotted Pipe-sliding Cover, Ungasketed	57	
Sample Well-slit Fabric Seal 10% Open	12[a]	
Stub Drain (1-inch diameter)[d]	1.2	$(D^2/125)$[b,c]
Vacuum Breaker (10-inch Diameter)		
Weighted Mechanical Actuation, Gasketed	0.7[a]	1
Weighted Mech Actuation, Ungasketed	0.9	

[a]If no specific information is available, this value can be assumed to represent the most common/typical deck fittings currently used.
[b]Column wells and ladder wells are not typically used with self-supported roofs.
[c]D = tank diameter (ft).
[d]Not used on welded contact internal floating decks.
[e]Not typically used on tanks with self-supporting fixed roofs.

TABLE D-8
DECK SEAM LENGTH FACTORS (S_D) FOR TYPICAL DECK CONSTRUCTIONS FOR INTERNAL FLOATING ROOF TANKS[a]

Deck Construction	Typical Deck Seam Length Factor (S_D), ft/ft^2
Continuous Sheet Construction[b]	
5 ft wide	0.20[c]
6 ft wide	0.17
7 ft wide	0.14
Panel Construction[d]	
5 x 7.5 ft rectangular	0.33
5 x 12 ft rectangular	0.28

[a]Deck seam loss applies to bolted decks only.
[b]S_D = 1/W, where W = sheet width (ft).
[c]If no specific information is available, this factor can be assumed to represent the most common bolted decks currently in use.
[d]S_D = (L+W)/LW, where W = panel width (ft) and L = panel length (ft).

TABLE D-9
RIM SEAL LOSS FACTORS (K_R and n)
FOR EXTERNAL FLOATING ROOF TANKS

Tank Construction and Rim Seal System	Average-fitting Seals	
	K_R [lb-mole/(mph)^n-ft-yr]	n (dimensionless)
Welded Tanks		
Mechanical-shoe Seal		
Primary Only	1.2*	1.5*
Shoe-mounted Secondary	0.8	1.2
Rim-mounted Secondary	0.2	1.0
Liquid-mounted Resilient-filled Seal		
Primary Only	1.1	1.0
Weather Shield	0.8	0.9
Rim-mounted Secondary	0.7	0.4
Vapor-mounted Resilient-filled Seal		
Primary Only	1.2	2.3
Weather Shield	0.9	2.2
Rim-mounted Secondary	0.2	2.6
Riveted Tanks		
Mechanical-shoe Seal		
Primary Only	1.3	1.5
Shoe-mounted Secondary	1.4	1.2
Rim-mounted Secondary	0.2	1.6

*If no specific information is available, a welded tank with an average-fitting mechanical-shoe primary seal can be used to represent the most common or typical construction and rim seal system in use.

TABLE D-10
AVERAGE ANNUAL WIND SPEED (v) FOR SELECTED U.S. LOCATIONS

Location	Wind Speed (mph)
Alabama	
Birmingham	7.2
Huntsville	8.2
Mobile	9.0
Montgomery	6.6
Alaska	
Anchorage	6.9
Annette	10.6
Barrow	11.8
Barter Island	13.2
Bethel	12.8
Bettles	6.7
Big Delta	8.2
Cold Bay	17.0
Fairbanks	5.4
Gulkana	6.8
Homer	7.6
Juneau	8.3
King Salmon	10.8
Kodiak	10.8
Kotzebue	13.0
McGrath	5.1
Nome	10.7
St. Paul Island	17.7
Talkeetna	4.8
Valdez	6.0
Yakutat	7.4
Arizona	
Flagstaff	6.8
Phoenix	6.3
Tucson	8.3
Winslow	8.9
Yuma	7.8
Arkansas	
Fort Smith	7.6
Little Rock	7.8
California	
Bakersfield	6.4
Blue Canyon	6.8
California (continued)	
Eureka	6.8
Fresno	6.3
Long Beach	6.4
Los Angeles (City)	6.2
Los Angeles International Airport	7.5
Mount Shasta	5.1
Sacramento	7.9
San Diego	6.9
San Francisco (City)	8.7
San Francisco Airport	10.6
Santa Maria	7.0
Stockton	7.5
Colorado	
Colorado Springs	10.1
Denver	8.7
Grand Junction	8.1
Pueblo	8.7
Connecticut	
Bridgeport	12.0
Hartford	8.5
Delaware	
Wilmington	9.1
District of Columbia	
Dulles Airport	7.4
National Airport	9.4
Florida	
Apalachicola	7.8
Daytona Beach	8.7
Fort Myers	8.1
Jacksonville	8.0
Key West	11.2
Miami	9.3
Orlando	8.5
Florida (continued)	
Pensacola	8.4
Tallahassee	6.3
Tampa	8.4
West Palm Beach	9.6
Georgia	
Athens	7.4
Atlanta	9.1
Augusta	6.5
Columbus	6.7
Macon	7.6
Savannah	7.9
Hawaii	
Hilo	7.2
Honolulu	11.4
Kahului	12.8
Lihue	12.2
Idaho	
Bosie	8.8
Pocatello	10.2
Illinois	
Cairo	8.5
Chicago	10.3
Moline	10.0
Peoria	10.0
Rockford	10.0
Springfield	11.2
Indiana	
Evansville	8.1
Fort Wayne	10.0
Indianapolis	9.6
South Bend	10.3
Iowa	
Des Moines	10.9

TABLE D-10 (Continued)

Location	Wind Speed (mph)	Location	Wind Speed (mph)	Location	Wind Speed (mph)
Iowa (continued)		Michigan (continued)		Nevada	
Sioux City	11.0	Houghton Lake	8.9	Elko	6.0
Waterloo	10.7	Lansing	10.0	Ely	10.3
		Muskegon	10.7	Las Vegas	9.3
		Sault Sainte Marie	9.3	Reno	6.6
Kansas				Winnemucca	8.0
Concordia	12.3				
Dodge City	14.0	Minnesota			
Goodland	12.6	Duluth	11.1	New Hampshire	
Topeka	10.2	International Falls	8.9	Concord	6.7
Wichita	12.3	Minneapolis-Saint Paul	10.6	Mount Washington	35.3
		Rochester	13.1		
		Saint Cloud	8.0		
Kentucky				New Jersey	
Cincinnati Airport	9.1			Atlantic City	10.1
Jackson	7.2	Mississippi		Newark	10.2
Lexington	9.3	Jackson	7.4		
Louisville	8.4	Meridian	6.1		
				New Mexico	
				Albuquerque	9.1
Louisiana		Missouri		Roswell	8.6
Baton Rouge	7.6	Columbia	9.9		
Lake Charles	8.7	Kansas City	10.8		
New Orleans	8.2	Saint Louis	9.7	New York	
Shreveport	8.4	Springfield	10.7	Albany	8.9
				Binghamton	10.3
				Buffalo	12.0
Maine		Montana		New York (Central Park)	9.4
Caribou	11.2	Billings	11.2	New York (JFK Airport)	12.0
Portland	8.8	Glasgow	10.8	New York (La Guardia Airport)	12.2
		Great Falls	12.8	Rochester	9.7
		Helena	7.8	Syracuse	9.5
Maryland		Kalispell	6.6		
Baltimore	9.2	Missoula	6.2		
				North Carolina	
Massachusetts		Nebraska		Asheville	7.6
Blue Hill Observatory	15.4	Grand Island	11.9	Cape Hatteras	11.1
Boston	12.4	Lincoln	10.4	Charlotte	7.5
Worcester	10.2	Norfolk	11.7	Greensboro-High Point	7.5
		North Platte	10.2	Raleigh	7.8
		Omaha	10.6	Wilmington	8.8
Michigan		Scotts Bluff	10.6		
Alpena	8.1	Valentine	9.7	North Dakota	
Detroit	10.2			Bismark	10.2
Flint	10.2				
Grand Rapids	9.8				

TABLE D-10 (Continued)

Location	Wind Speed (mph)
North Dakota (continued)	
Fargo	12.3
Williston	10.1
Ohio	
Akron	9.8
Cleveland	10.6
Columbus	8.5
Dayton	9.9
Mansfield	11.0
Toledo	9.4
Youngstown	9.9
Oklahoma	
Oklahoma City	12.4
Tulsa	10.3
Oregon	
Astoria	8.6
Eugene	7.6
Medford	4.8
Pendleton	8.7
Portland	7.9
Salem	7.1
Sexton Summit	11.8
Pennsylvania	
Allentown	9.2
Avoca	8.3
Erie	11.3
Harrisburg	7.6
Philadelphia	9.5
Pittsburgh Int'l. Airport	9.1
Williamsport	7.8
Puerto Rico	
San Juan	8.4
Rhode Island	
Providence	10.6
South Carolina	
Charleston	8.6
Columbia	6.9
Greenville-Spartanburg	6.9
South Dakota	
Aberdeen	11.2
Huron	11.5
Rapid City	11.3
Sioux Falls	11.1
Tennessee	
Bristol-Johnson City	5.5
Chattanooga	6.1
Knoxville	7.0
Memphis	8.9
Nashville	8.0
Oak Ridge	4.4
Texas	
Abilene	12.0
Amarillo	13.6
Austin	9.2
Brownsville	11.5
Corpus Christi	12.0
Dalls-Fort Worth	10.8
Del Rio	9.9
El Paso	8.9
Galveston	11.0
Houston	7.9
Lubbock	12.4
Midland-Odessa	11.1
Port Arthur	9.8
San Angelo	10.4
San Antonio	9.3
Victoria	10.1
Waco	11.3
Wichita Falls	11.7
Utah	
Salt Lake City	8.9
Vermont	
Burlington	8.9
Virginia	
Lynchburg	7.7
Norfolk	10.7
Richmond	7.7
Roanoke	8.1
Washington	
Olympia	6.7
Quillayute	6.1
Seattle Int'l. Airport	9.0
Spokane	8.9
Walls Walls	5.3
Yakima	7.1
West Virginia	
Beckley	9.1
Charleston	6.4
Elkins	6.2
Huntington	6.6
Wisconsin	
Green Bay	10.0
La Crosse	8.8
Madison	9.9
Milwaukee	11.6
Wyoming	
Casper	12.9
Cheyenne	13.0
Lander	6.8
Sheridan	8.0

TABLE D-11
EXTERNAL FLOATING ROOF-FITTING LOSS FACTORS (K_{Fa}, K_{Fb}, and m) AND TYPICAL NUMBER OF ROOF FITTINGS (N_F)

Fitting type and construction details	Loss Factors: K_{Fa} (lb-mole/yr)	K_{Fb} [lb-mole/(mph)^m-yr]	m (dimensionless)	Typical number fittings, N_F
Access hatch (24-inch diameter well)				1
Bolted cover, gasketed	0	0	0[a]	
Unbolted cover, ungasketed	2.7	7.1	1.0	
Unbolted cover, gasketed	2.9	0.41	1.0	
Unslotted guide-pole well (8-inch diameter unslotted pole, 21-inch diameter well)				1
Ungasketed sliding cover	0	67	0.98 [a]	
Gasketed sliding cover	0	3.0	1.4	
Slotted guide-pole/sample well (8 inch diameter slotted pole, 21-inch diameter well)				b
Ungasketed sliding cover, without float	0	310	1.2	
Ungasketed sliding cover, with float	0	29	2.0	
Gasketed sliding cover, without float	0	260	1.2	
Gasketed sliding cover, with float	0	8.5	2.4	
Gauge-float well (20-inch diameter)				1
Unbolted cover, ungasketed	2.3	5.9	1.0[a]	
Unbolted cover, gasketed	2.4	0.34	1.0	
Bolted cover, gasketed	0	0	0	
Gauge-hatch/sample well (8-inch diameter)				1
Weighted mechanical actuation, gasketed	0.95	0.14	1.0[a]	
Weighted mechanical actuation, ungasketed	0.91	2.4	1.0	
Vacuum breaker (10-inch diameter well)				N_{F6} (Table D-12)
Weighted mechanical actuation, gasketed	1.2	0.17	1.0[a]	
Weighted mechanical actuation, ungasketed	1.1	3.0	1.0	
Roof drain (3-inch diameter)				N_{F7} (Table D-12)
Open	0	7.0	1.4[c]	
90% closed	0.51	0.81	1.0	
Roof leg (3-inch diameter)				N_{F8} (Table D-13)
Adjustable, pontoon area	1.5	0.20	1.0[a]	
Adjustable, center area	0.25	0.067	1.0[a]	
Adjustable, double-deck roofs	0.25	0.067	1.0	
Fixed	0	0	0	
Roof leg (2-1/2 inch diameter)				N_{F8} (Table D-13)
Adjustable, pontoon area	1.7	0	0	
Adjustable, center area	0.41	0	0	
Adjustable, double-deck roofs	0.41	0	0	
Fixed	0	0	0	

TABLE D-11 (Continued)

Fitting type and construction details	Loss Factors			Typical number fittings, N_F
	K_{Fa} (lb-mole/yr)	K_{Fb} [lb-mole/(mph)^m-yr]	m (dimensionless)	
Rim vent (6-inch diameter)				1[e]
Weighted mechanical actuation, gasketed	0.71	0.10	1.0[a]	
Weighted mechanical actuation, ungasketed	0.68	1.8	1.0	

Note: The roof-fittin[illegible] [illegible]s factors, K_{Fa}, K_{Fb}, and m, may only be used for wind speeds from 2 to 15 miles per hour.

[a]If no specific information is available, this value can be assumed to represent the most common or typical roof fitting currently in use.
[b]A slotted guide-pole/sample well is an optional fitting and is not typically used.
[c]Roof drains that drain excess rainwater into the product are not used on pontoon floating roofs. They are, however, used on double-deck floating roofs and are typically left open.
[d]The most common roof leg diameter is 3 inches. The loss factors for 2-1/2 inch diameter roof legs are provided for use if this smaller size roof leg is used on a particular floating roof.
[e]Rim vents are used only with mechanical-shoe primary seals.

TABLE D-13
EXTERNAL FLOATING ROOF TANKS: TYPICAL NUMBER OF ROOF LEGS (N_{F8})

Tank diameter, *D* (feet)*	Pontoon roof		Number of legs on double-deck roof
	Number of pontoon legs	Number of center legs	
30	4	2	6
40	4	4	7
50	6	6	8
60	9	7	10
70	13	9	13
80	15	10	16
90	16	12	20
100	17	16	25
110	18	20	29
120	19	24	34
130	20	28	40
140	21	33	46
150	23	38	52
160	26	42	58
170	27	49	66
180	28	56	74
190	29	62	82
200	30	69	90
210	31	77	98
220	32	83	107
230	33	92	115
240	34	101	127
250	35	109	138
260	36	118	149
270	36	128	162
280	37	138	173
290	38	148	186
300	38	156	200
310	39	168	213
320	39	179	226
330	40	190	240
340	41	202	255
350	42	213	270

TABLE D-12
EXTERNAL FLOATING ROOF TANKS: TYPICAL NUMBER OF VACUUM BREAKERS (N_{F6}) AND ROOF DRAINS (N_{F7})

Tank diameter D (feet)	Number of vacuum breakers, N_{F6}		Number of roof drains, N_{F7} (double-deck roof)
	Pontoon roof	Double-deck roof	
50	1	1	1
100	1	1	1
150	2	2	2
200	3	2	3
250	4	3	5
300	5	3	7
350	6	4	--
400	7	4	--

Note: This table was derived from a survey of users and manufacturers. The actual number of vacuum breakers may vary greatly depending on throughput and manufacturing prerogatives. The actual number of roof drains may also vary greatly depending on the design rainfall and manufacturing prerogatives. For tanks more than 300 feet in diameter, actual tank data or the manufacturer's recommendations may be needed for the number of roof drains. This table should not supersede information based on actual tank data.

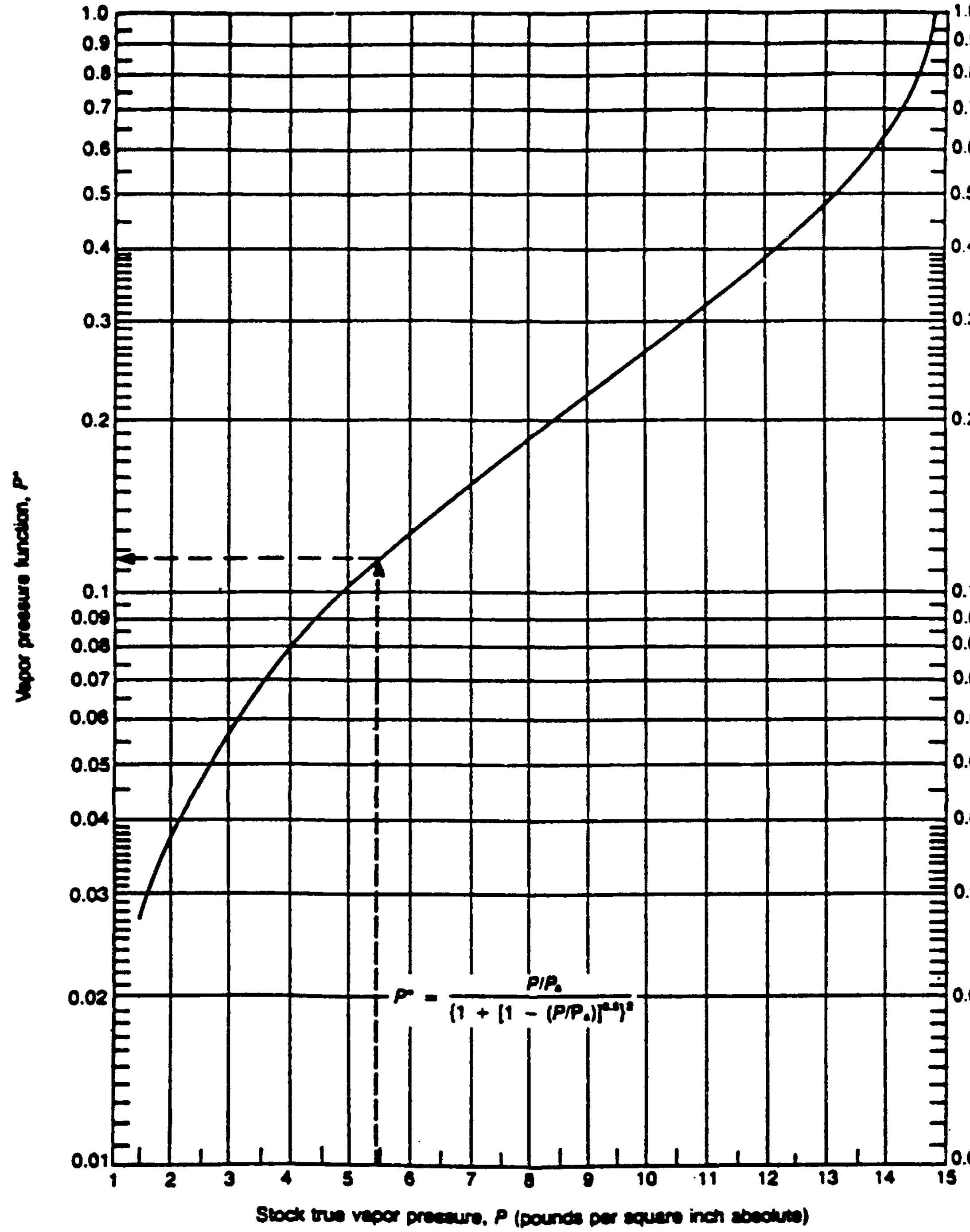
If the actual diameter is between the diameters listed, the closest diameter listed should be used. If the actual diameter is midway between the diameters listed, the next larger diameter should be used.
Roof drains that drain excess rainwater into the product are not used on pontoon floating roofs. They are, however, used on double-deck floating roofs and are typically left open.

TABLE D-13 (Continued)

Tank diameter, D (feet)*	Pontoon roof: Number of pontoon legs	Pontoon roof: Number of center legs	Number of legs on double-deck roof
360	44	226	285
370	45	238	300
380	46	252	315
390	47	266	330
400	48	281	345

Note: This table was derived from a survey of users and manufacturers. The actual number of roof legs may vary greatly depending on age, style of floating roof, loading specifications, and manufacturing prerogatives. This table should not supersede information based on actual tank data.

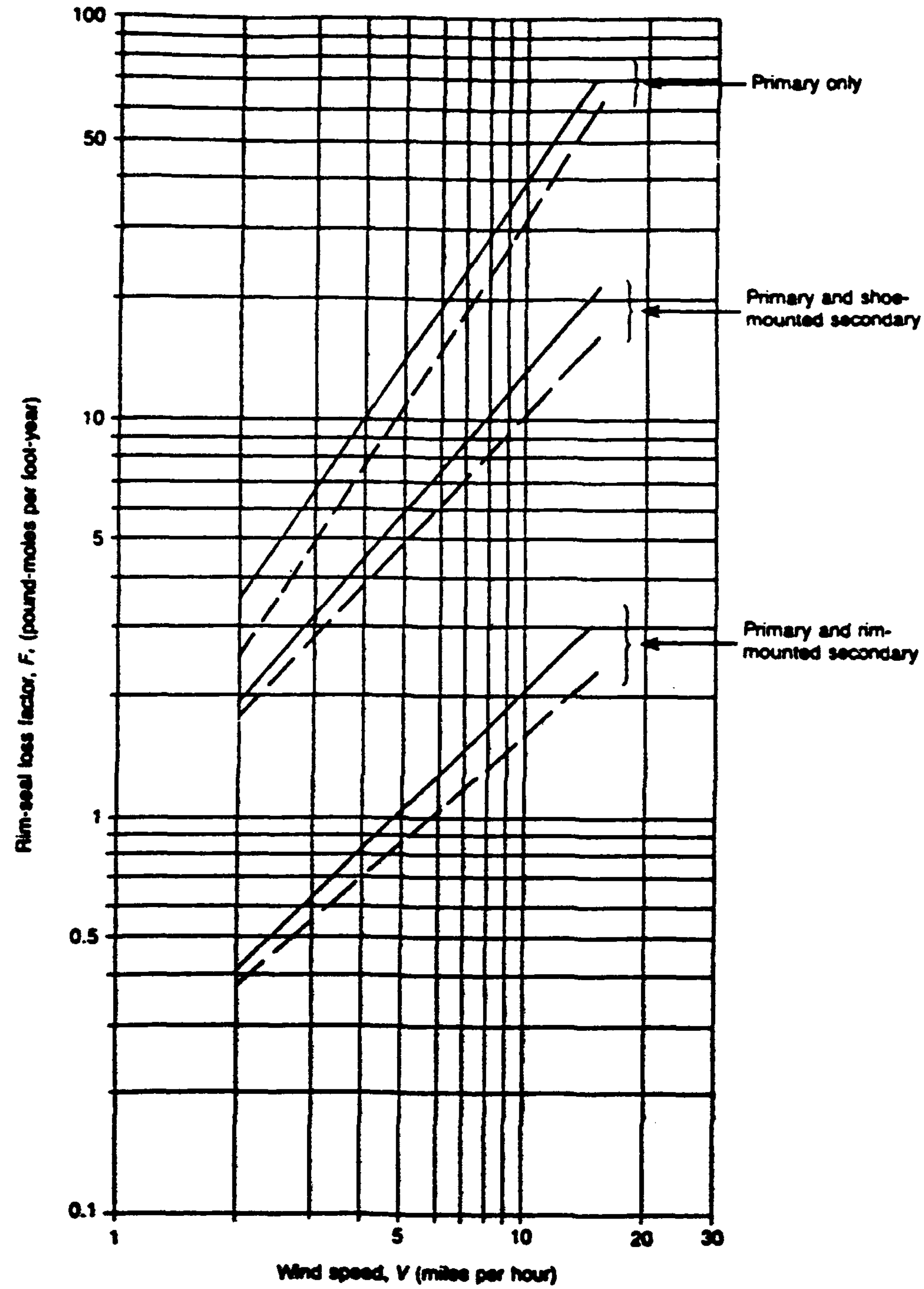
*If the actual diameter is between the diameters listed, the closest diameter listed should be used. If the actual diameter is midway between the diameters listed, the next larger diameter should be used.



Notes:

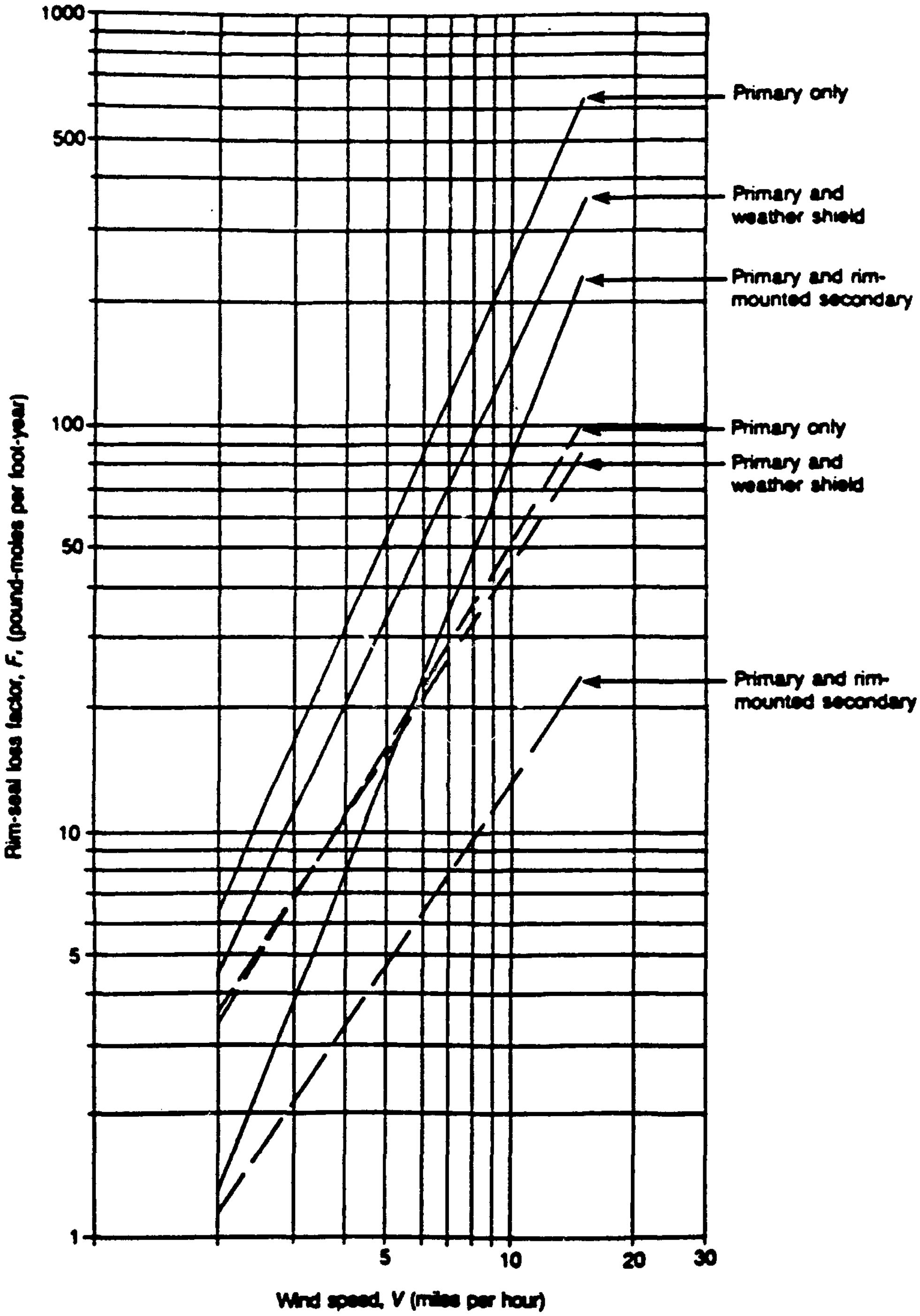
1. Broken line illustrates sample problem for $P = 5.4$ pounds per square inch absolute.
2. Curve is for atmospheric pressure, P_a, equal to 14.7 pounds per square inch absolute.

FIGURE D-1
VAPOR PRESSURE FUNCTION



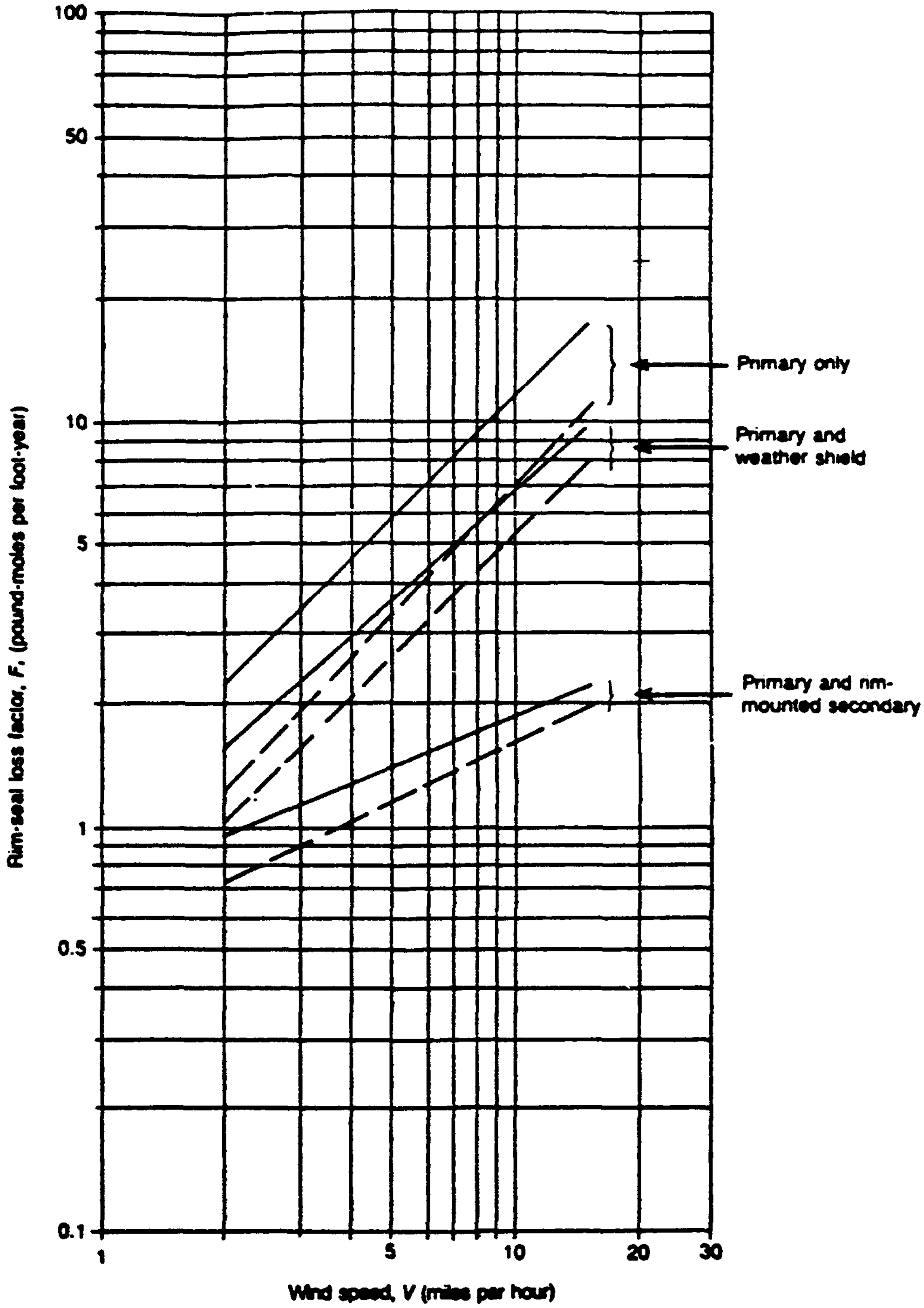
Note: Solid line indicates average-fitting seal; broken line indicates tight-fitting seal; $F_r = K_r V^n$.

FIGURE D-2
RIM SEAL LOSS FACTOR FOR A WELDED TANK WITH A MECHANICAL-SHOE PRIMARY SEAL



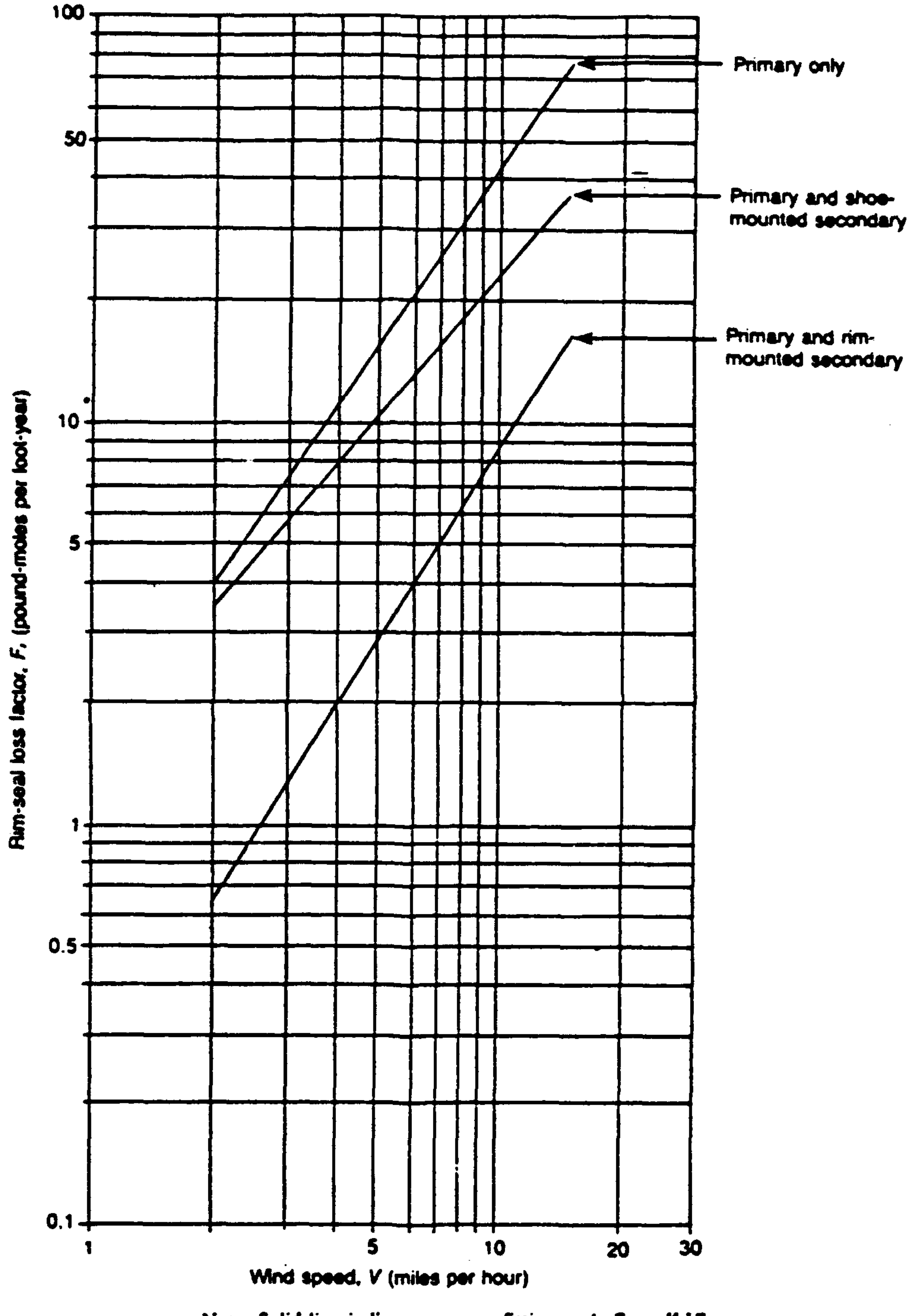
Note: Solid line indicates average-fitting seal; broken line indicates tight-fitting seal; $F_r = K_r V^n$.

FIGURE D-3
RIM SEAL LOSS FACTOR FOR A WELDED TANK WITH A VAPOR-MOUNTED, RESILIENT-FILLED PRIMARY SEAL



Note: Solid line indicates average-fitting seal; broken line indicates tight-fitting seal; $F_r = K_r V^n$.

FIGURE D-4
RIM SEAL LOSS FACTOR FOR A WELDED TANK WITH A LIQUID-MOUNTED, RESILIENT-FILLED PRIMARY SEAL



Note: Solid line indicates average-fitting seal: $F_r = K_r V^n$.

FIGURE D-5
RIM SEAL LOSS FACTOR FOR A RIVETED TANK WITH A
MECHANICAL-SHOE PRIMARY SEAL

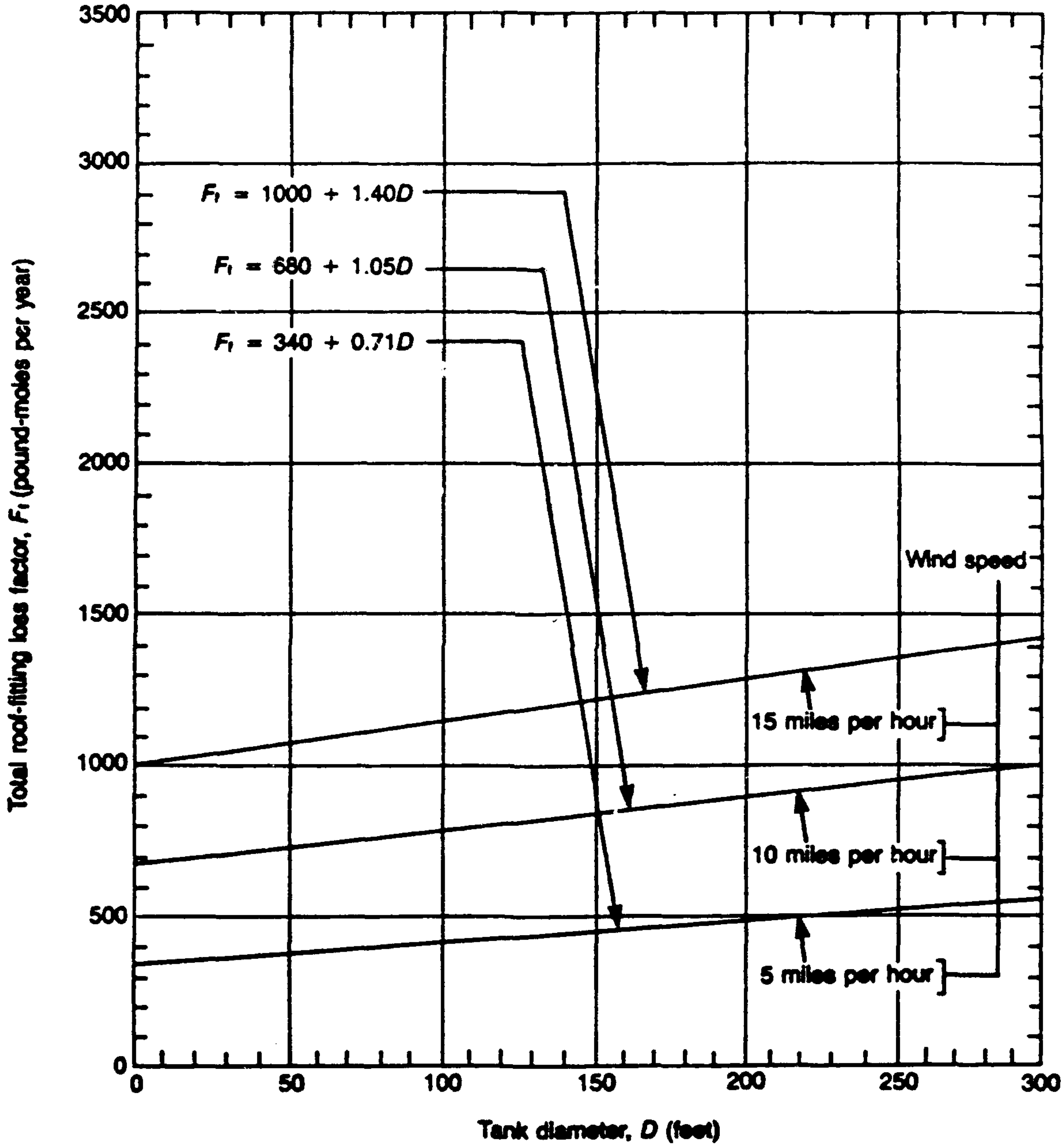


FIGURE D-6
TOTAL ROOF-FITTING LOSS FACTOR FOR TYPICAL FITTINGS ON PONTOON FLOATING ROOFS

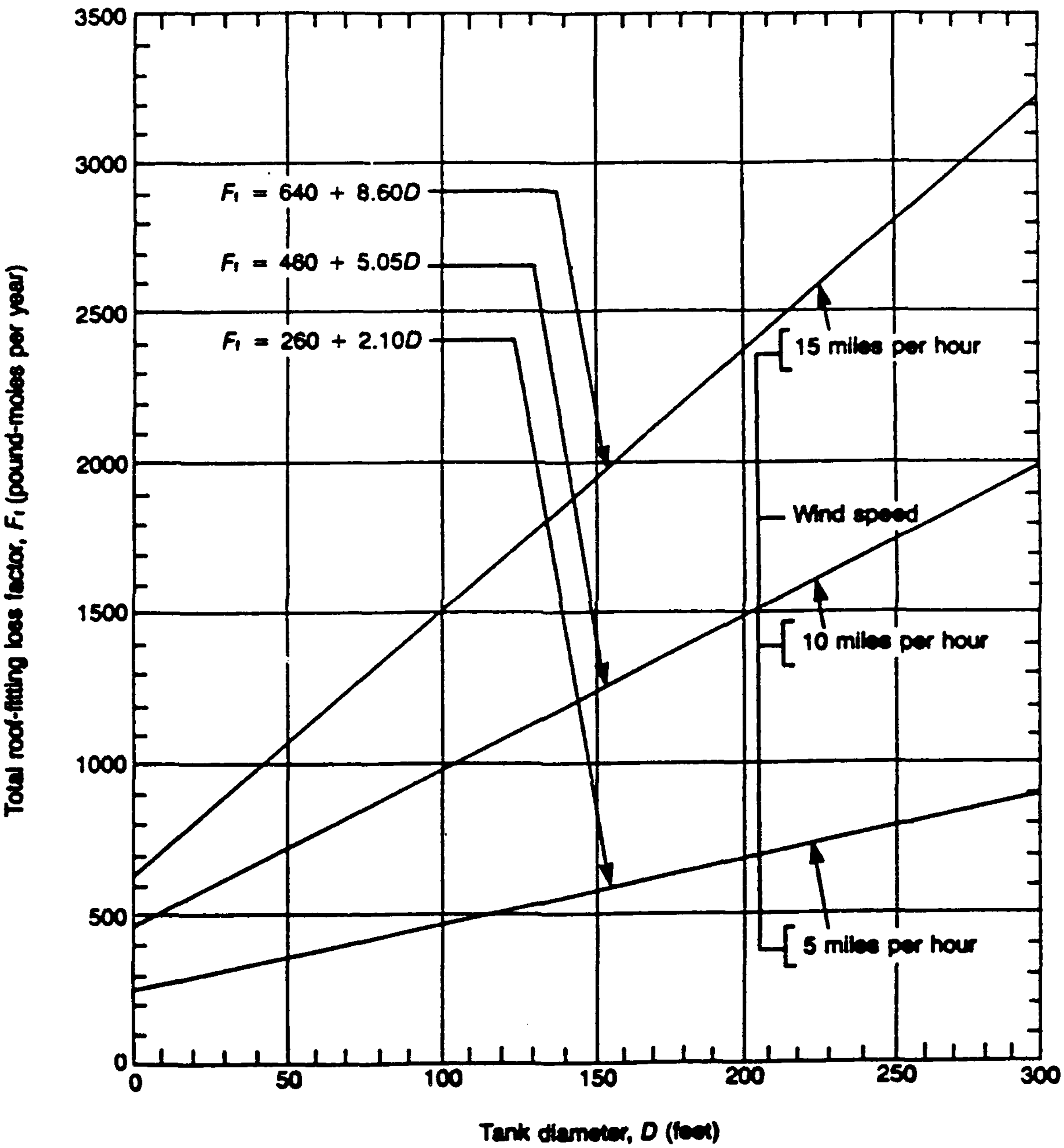


FIGURE D-7
TOTAL ROOF-FITTING LOSS FACTOR FOR TYPICAL
FITTINGS ON DOUBLE-DECK FLOATING ROOFS

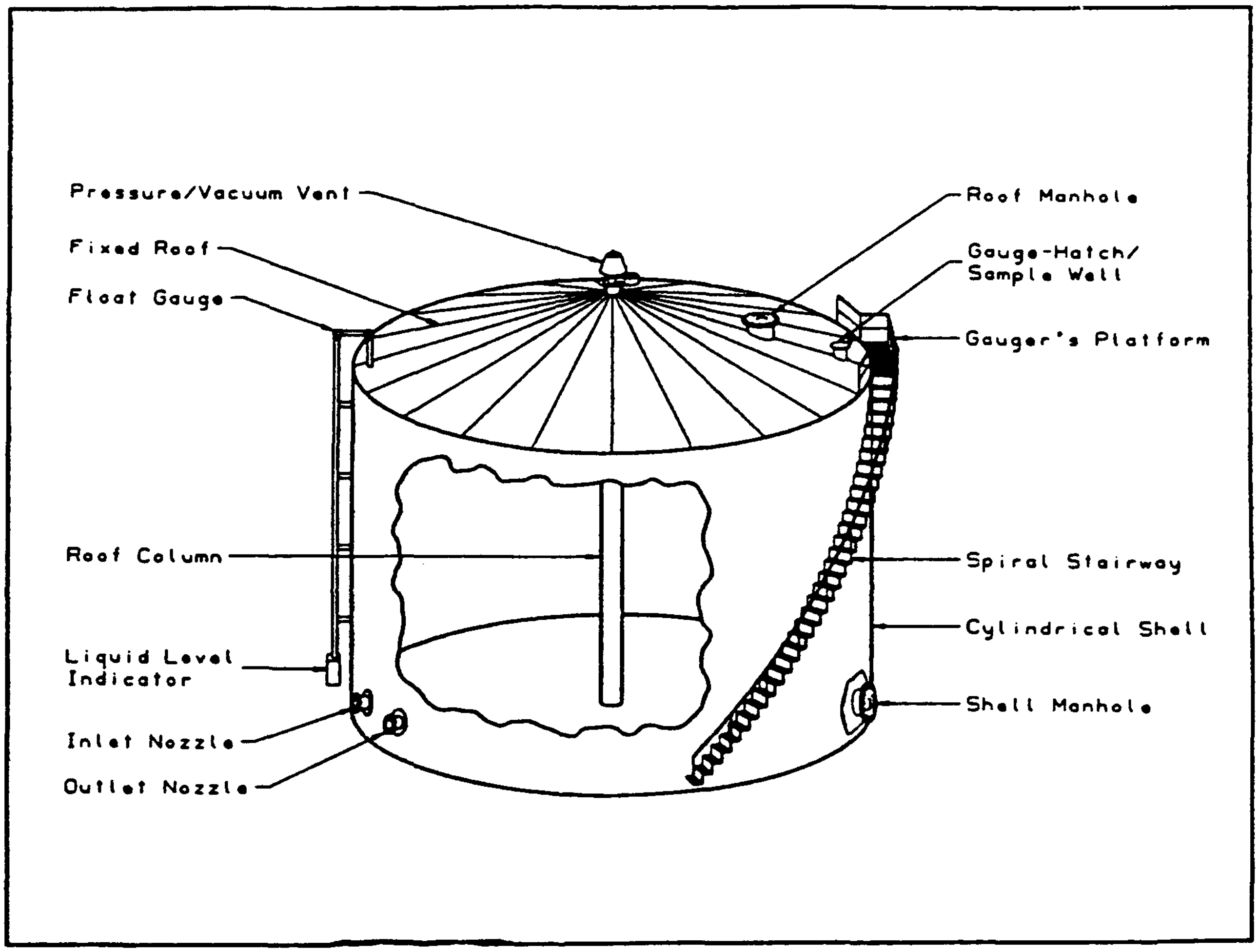
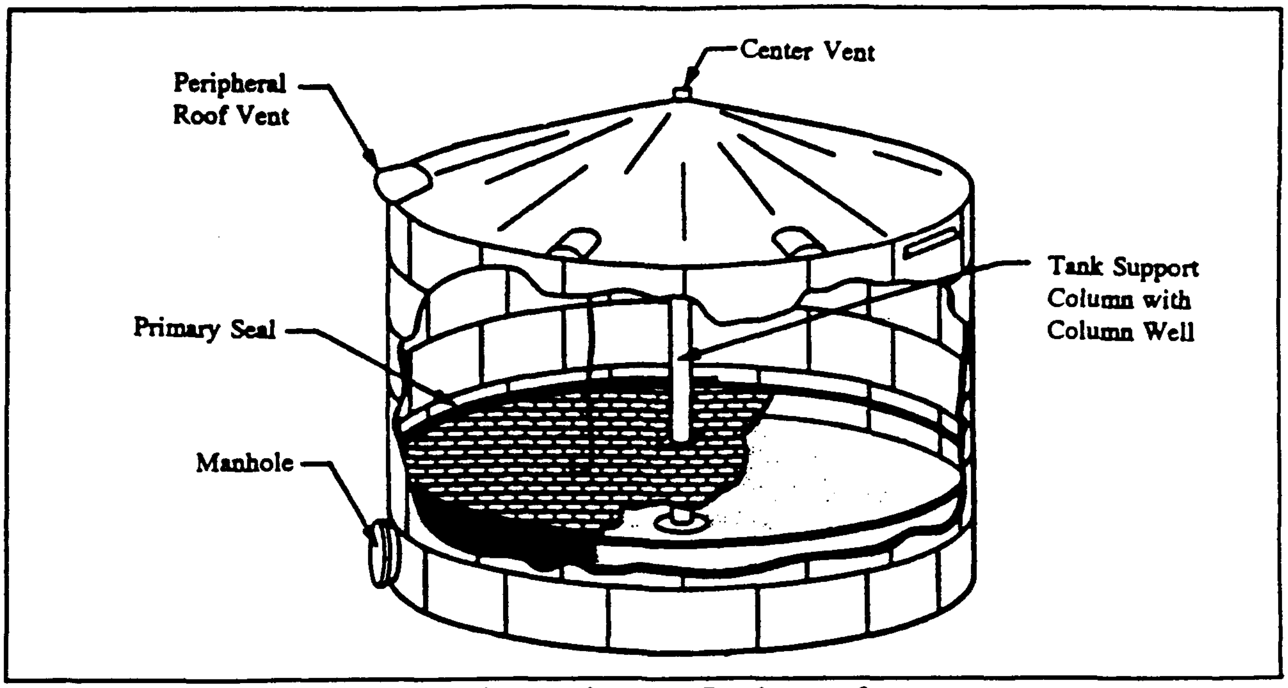
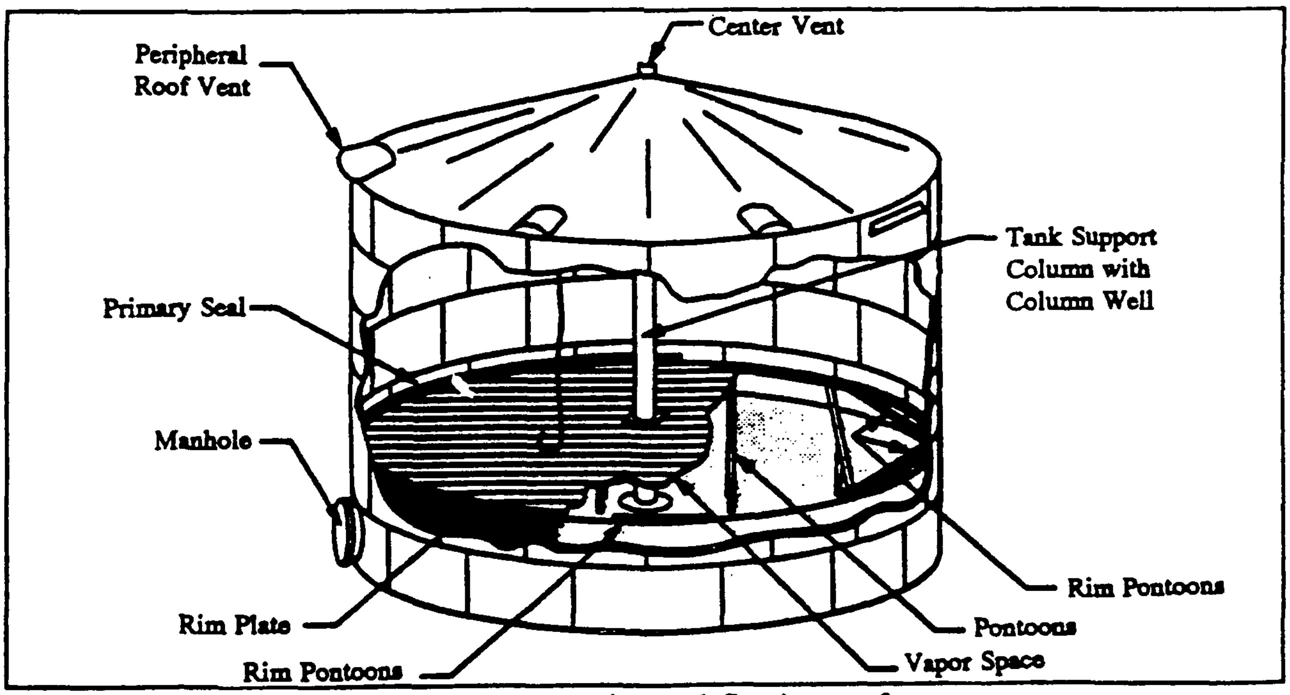


FIGURE D-8
TYPICAL FIXED ROOF TANK



a. Contact internal floating roof



b. Noncontact internal floating roof.

FIGURE D-9
INTERNAL FLOATING ROOF TANK

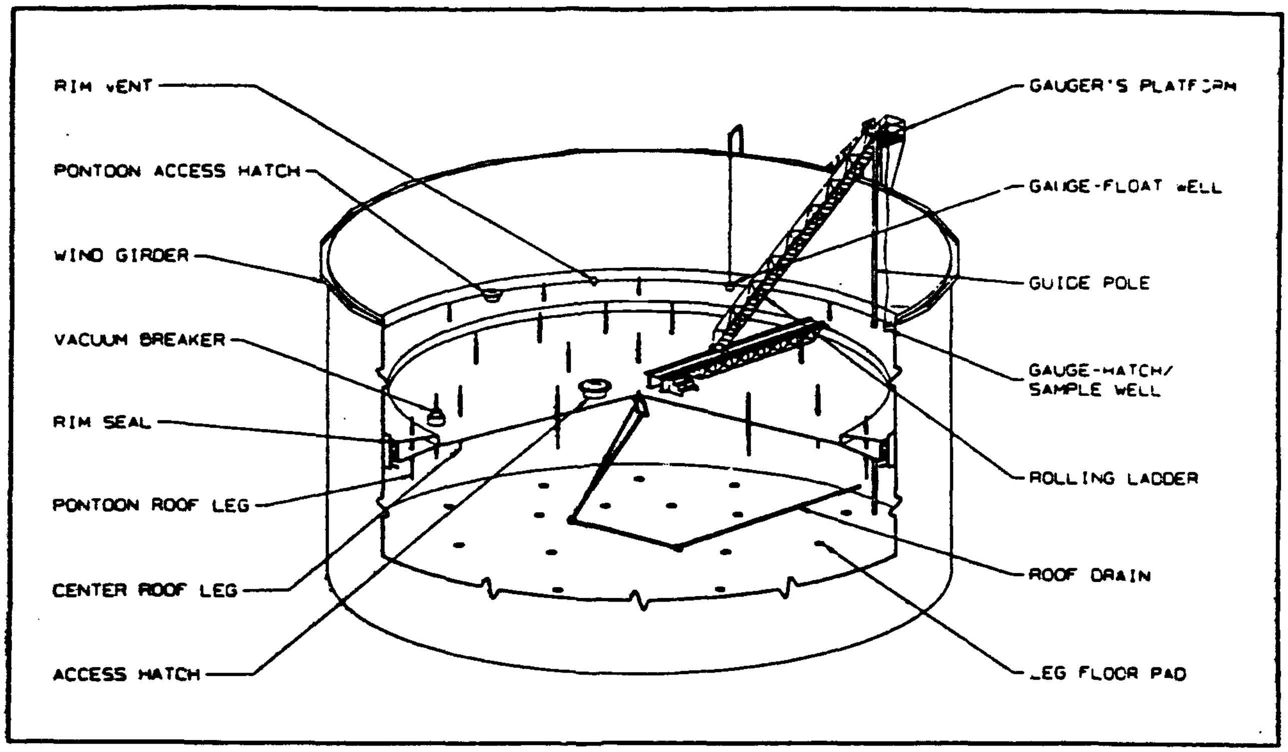


FIGURE D-10
EXTERNAL FLOATING ROOF TANK (PONTOON TYPE)

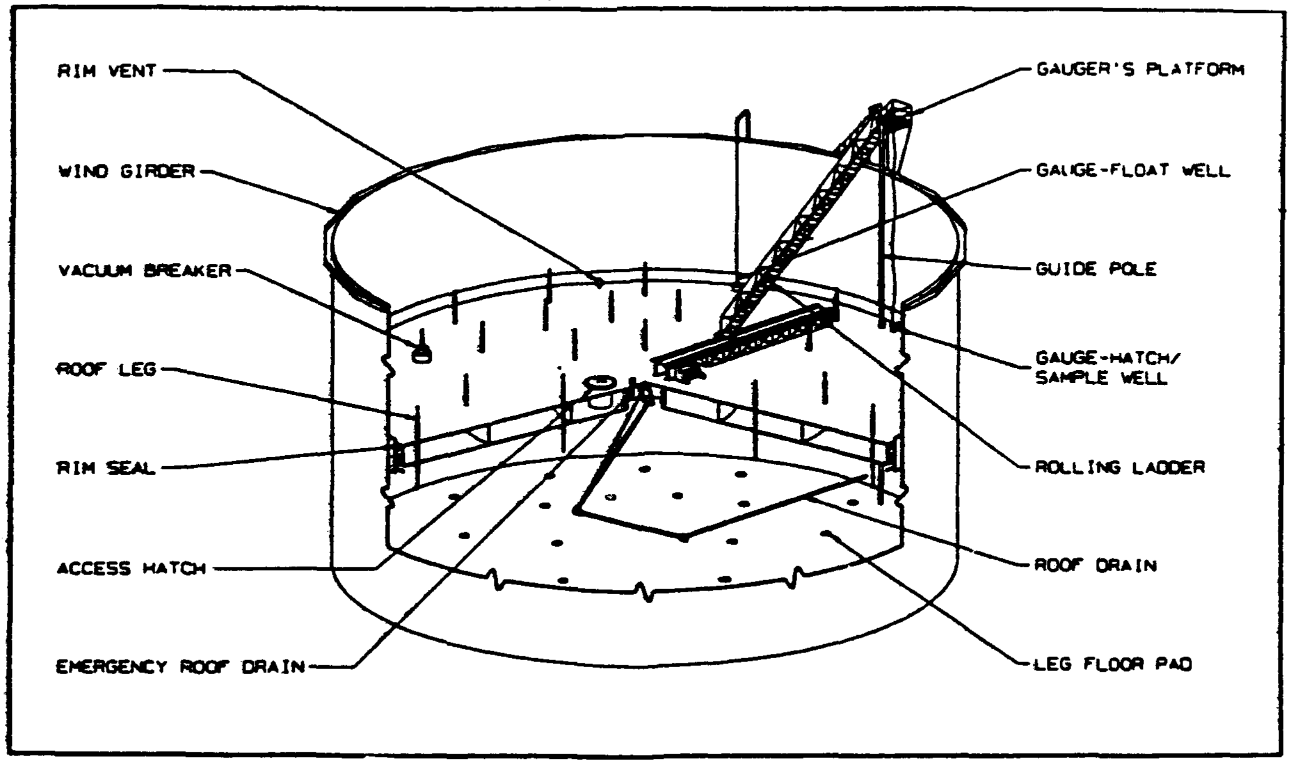


FIGURE D-11
EXTERNAL FLOATING ROOF TANK (DOUBLE-DECK TYPE)

E. FUEL TRANSFER EVAPORATIVE LOSSES

1. BACKGROUND

a. Fuel transfer evaporative losses occur during the fuel loading of tank trucks, automobile tanks (vehicle refueling), and aircraft tanks (aircraft refueling). As fuel is loaded into a tank (or tank truck), vapors in the tank are displaced and exhausted out. On Air Force installations, fuel loaded into tank trucks usually comes from storage tanks on base but also may come from aircraft tanks during aircraft defueling procedures. The amount of evaporative losses during transfer operations depends on the method of loading and the type of vapor control system, if any, being used.

b. There are two different methods of fuel loading, splash loading and submerged loading.

(1) In the splash loading method, the fill pipe dispensing the fuel is lowered only partway into the tank, above the liquid level. Significant turbulence and vapor/liquid contact occur during splash loading, resulting in high levels of vapor generation and loss.

(2) Two types of submerged loading currently exist, the submerged fill pipe method and the bottom loading method. In the submerged fill pipe method, the fill pipe extends almost to the bottom of the tank. In the bottom loading method, a permanent fill pipe is attached to the bottom of the tank. For both types of submerged loading, the fill pipe opening is below the liquid surface level. Liquid turbulence is controlled significantly during submerged loading, resulting in much lower vapor generation than encountered during splash loading. Schematics of splash loading, submerged fill pipe loading, and bottom loading are shown if Figures E-1, E-2, and E-3, respectively.

c. Vapor control systems can significantly reduce the amount of vapors exhausted to the atmosphere during fuel loading operations. The most common type of vapor control is vapor recovery, also known as vapor balance. During the transfer of fuel from a tank truck to a tank, vapors displaced from the tank can be sent to the tank truck through a vapor recovery line. This is known as Stage I Vapor Recovery. During the transfer of fuel from a storage tank to a motor vehicle (e.g., vehicle refueling at a service station), vapors displaced from the vehicle tank can be sent to the storage tank through a vapor recovery line. This is known as Stage II Vapor Recovery. Stage I and II Vapor Recovery are most common, and sometimes mandatory, in ozone nonattainment areas. A schematic of Stage I and Stage II Vapor Recovery systems is shown in Figure E-4. During the transfer of fuel from a tank to a tank truck, vapors displaced from the tank truck can be recovered with the use of special vapor recovery systems, such as refrigeration, absorption, adsorption, and/or compression. The recovered product is then piped back to the tank. A schematic of vapor recovery during loading of a tank truck is shown in Figure E-5. Vapors from tank truck loading can also be controlled through combustion in a thermal oxidation unit, with no product recovery.

d. The amount of evaporative losses during the loading of a tank truck is also influenced by the recent history of the tank. If the tank has just been cleaned and vented, it will contain vapor-free air. However, if the tank truck has just carried fuel and has not been vented, it will contain volatile organic vapors, which are expelled during the loading operation along with newly generated vapors.

2. CALCULATIONS: Contact the Civil Engineering Squadron for physical data on vapor control systems and Base Supply Fuels Management for data concerning fuel transfers. Any other independent fuel dispensing facilities, such as the Base Exchange Gas Station, must also be considered. The following equation is used:

$$E = (F_T)(L_L)$$

Where:

E = Annual VOC emissions (lb/yr)
F_T = Fuel transferred (1000 gal/yr)
L_L = Loading loss (lb/1000 gal)

$$L_L = (12.46SPM/T)[1-(eff/100)]$$

Where:

12.46 = constant
S = Saturation factor, see Table E-1
P = True vapor pressure (psia) of liquid loaded, use the temperature of the bulk liquid loaded and either Table D-1 or Figure D-13
M = Molecular weight of vapors (lb/lb-mole), see Table D-1
T = Temperature of bulk liquid loaded (R), see equation A-13
eff = Control efficiency (%)

3. EXAMPLE PROBLEM: Calculate the annual fuel transfer evaporative emissions associated with aircraft fueling operations on base. Approximately 4,450,000 gallons of JP-4 per year is used to refuel aircraft. The fuel is transferred from storage tanks to the aircraft via tank trucks. The transfer of fuel from storage tanks to tank trucks is accomplished using the submerged fill pipe method and a vapor recovery system with a control efficiency of 95%. The transfer from tank trucks to aircraft is accomplished using the splash loading method and no vapor recovery. Additionally, approximately 65,000 gallons of JP-4 per year are defueled from aircraft into tank trucks. The transfer from aircraft to tank trucks is accomplished using the submerged fill pipe method and vapor recovery. The annual average bulk JP-4 temperature is 60 F. Tank trucks are not cleaned prior to fuel transfers.

a. Emissions from the transfer of fuel from storage tanks to tank trucks is calculated as follows: S = 1.00, P = 1.3, M = 80, T = 520, eff = 95

$$L_L = [(12.46)(1.00)(1.3)(80)/520] \times [1-(95/100)] = 0.1246 \text{ lb/1000 gal}$$

$$E = (4{,}450 \text{ 1000 gal/yr})(0.1246 \text{ lb/1000 gal}) = \mathbf{555\ lb}$$

b. Emissions from the transfer of fuel from tank trucks to aircraft is calculated as follows: S = 1.45, P = 1.3, M = 80, T = 520, eff = 0

$$L_L = [(12.46)(1.45)(1.3)(80)/520] \times [1-(0/100)] = 3.6134 \text{ lb/1000 gal}$$

$$E = (4{,}450 \text{ 1000 gal/yr})(3.6134 \text{ lb/1000 gal}) = \mathbf{16{,}080\ lb/yr}$$

c. Emissions from the transfer of fuel from aircraft to tank trucks is calculated as follows: $S = 0.60$, $P = 1.3$, $M = 80$, $T = 520$, $eff = 0$

$$L_L = [(12.46)(0.60)(1.3)(80)/520] \times [1-(0/100)] = 1.4952 \text{ lb/1000 gal}$$

$$E = (65\ 1000 \text{ gal/yr})(1.4952 \text{ lb/1000 gal}) = \mathbf{97\ lb/yr}$$

d. The *total* VOC emissions from aircraft refueling/defueling operations is:

555 + 16,080 +97 = **16,732 lb/yr**

TABLE E-1
SATURATION (S) FACTORS FOR
CALCULATING FUEL LOADING LOSSES

Mode of Fuel Loading	S Factor
Submerged Loading of a Clean (vapor free) Tank Truck	0.50
Submerged Loading: Dedicated Normal Service	0.60
Submerged Loading: Dedicated Vapor Balance Service	1.00
Splash Loading of a Clean (vapor free) Tank Truck	1.45
Splash Loading: Dedicated Normal Service	1.45
Splash Loading: Dedicated Vapor Balance Service	1.00

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Texas Air Control Board. Fact Sheet: Stage II Vapor Recovery. December 1992.

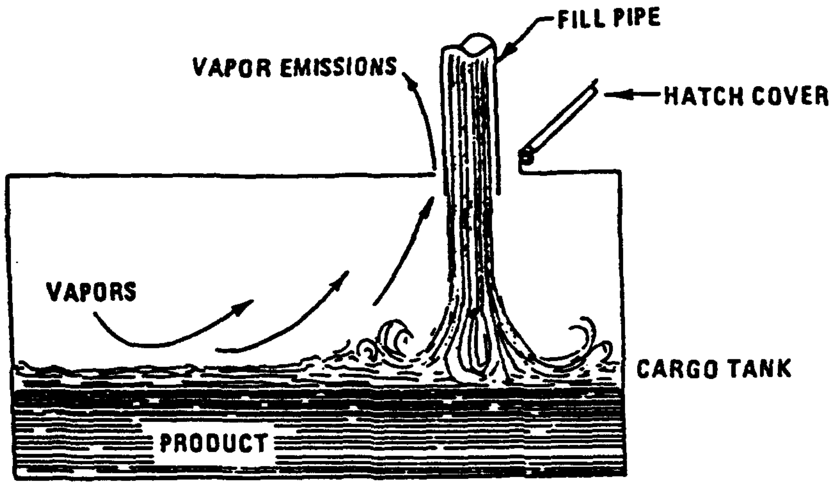

FIGURE E-1. SPLASH LOADING METHOD.

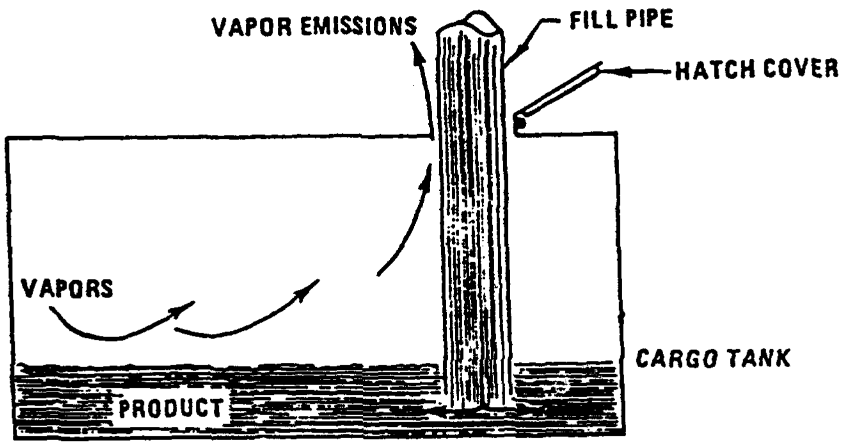

FIGURE E-2. SUBMERGED FILL PIPE.

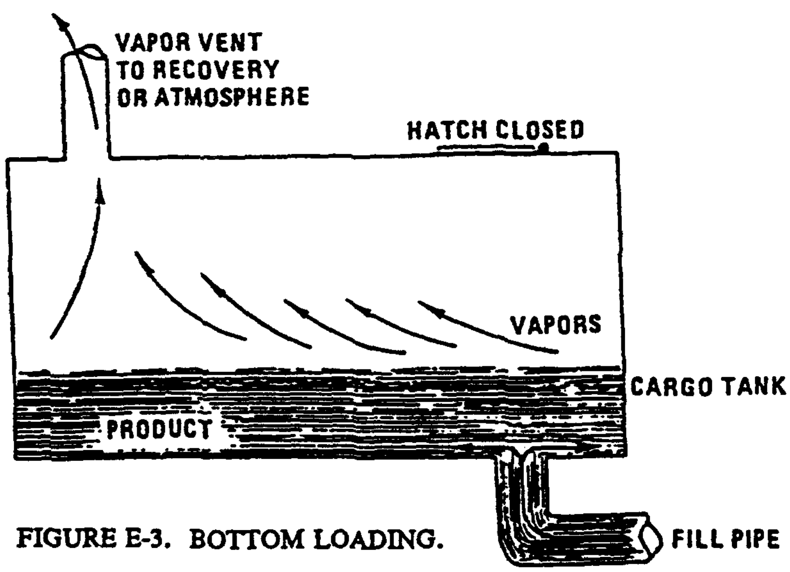

FIGURE E-3. BOTTOM LOADING.

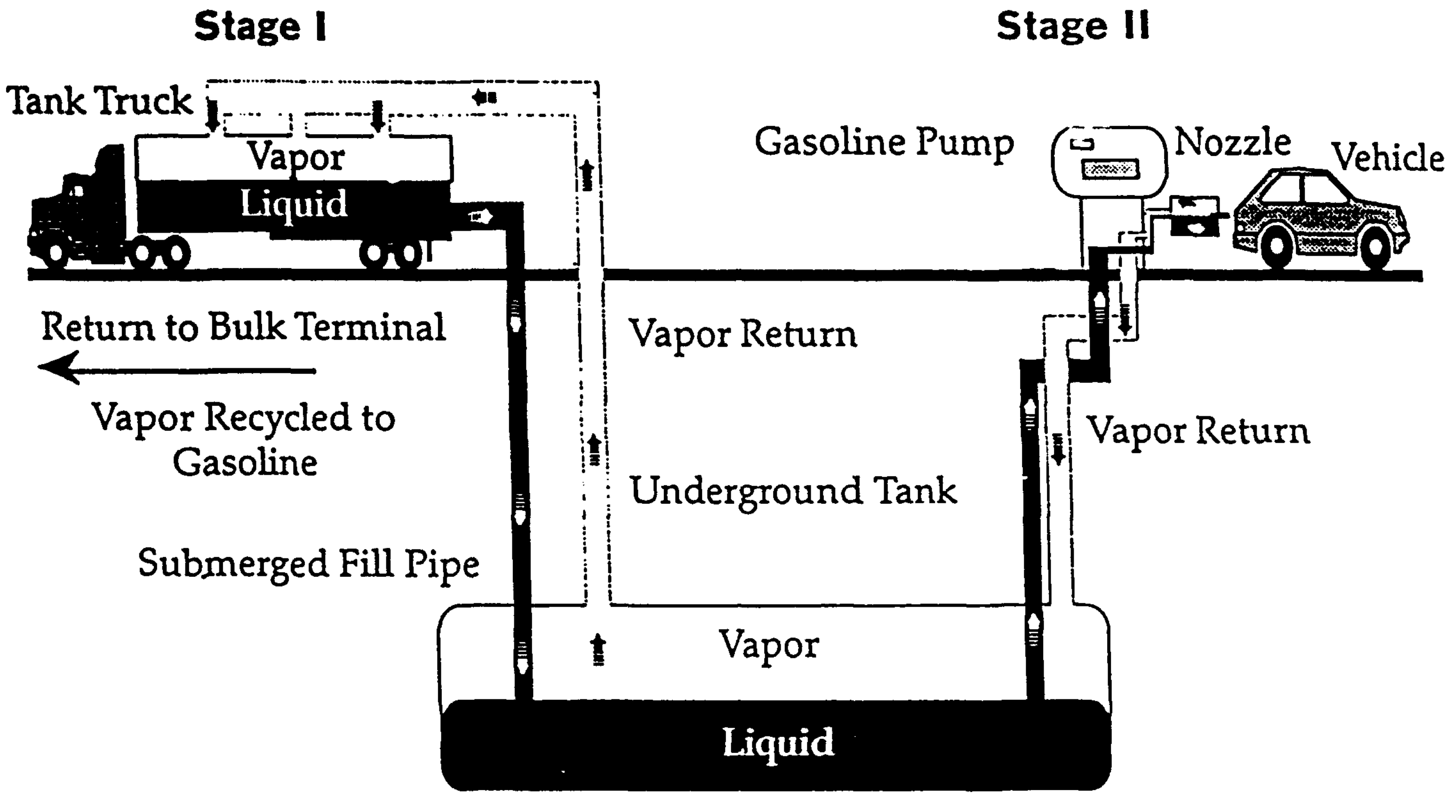

FIGURE E-4. STAGE I AND STAGE II VAPOR RECOVERY.

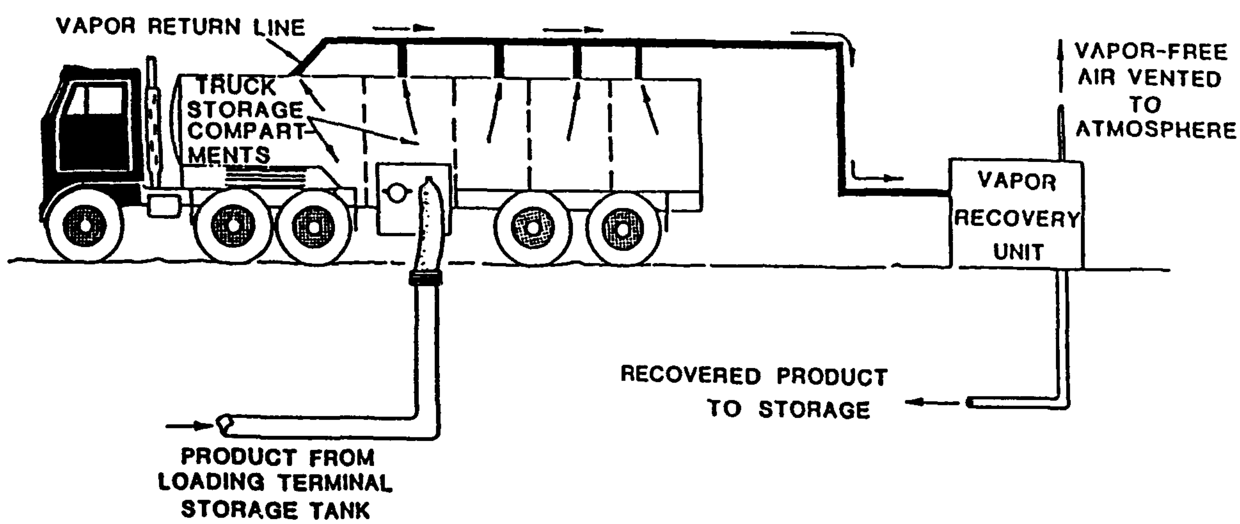

FIGURE E-5. TANK TRUCK LOADING WITH VAPOR RECOVERY.

F. SURFACE COATINGS

1. BACKGROUND

a. Surface coatings containing hydrocarbon (organic) solvents are a major contributor to uncontrolled VOC emissions. They include a diversity of lacquer and enamel paints, primers, varnishes, shellacs, thinners, adhesives, etc. Significant users of surface coatings on Air Force installations include Corrosion Control facilities, Civil Engineering paint shops, Vehicle and Munitions Maintenance facilities, and similar areas. The widespread use of these uncontrolled materials (to some degree, in most industrial and many administrative areas) is a cause for general concern.

b. The emission of VOCs occurs from the evaporation of the coatings' hydrocarbon vehicles or solvents (thinners) during the application process such as brushing, rolling, spraying, dipping; and while drying. Emissions are also created during the uncontrolled mixing and thinning of surface coatings, during application equipment cleaning operations, and when containers are left uncovered. Primary compounds of interest include aliphatic and aromatic hydrocarbons, alcohols, esters, and ketones. The EPA's definition of VOCs does not include methane, ethane, methylene chloride, 1,1,1-trichloroethane (methyl chloroform), hydrochlorofluorocarbons (HCFCs), and chlorofluorocarbons (CFCs).

2. CALCULATIONS AND EXAMPLE PROBLEMS: VOC emissions may be quantified by employing either of two methods. Method 1 is presently the preferred method for criteria pollutants. Although method 2 is not required, future requirements under the Air Toxics provisions of Title III, CAA-90 will require this or a similar method for estimating hazardous air pollutant emissions. The following sources should be considered when gathering VOC source and usage data: Bioenvironmental Engineering case files, Hazardous Materials (HAZMAT) Pharmacy Cell, Issue Exception (IEX) Coding System, and Base Supply.

a. Method 1:

(1) The following equation is used for Method 1: $E = CF$

Where:

E = VOC emissions (lb/yr)
C = Consumption of surface coating (gal/yr)
F = Emission Factor (lb VOC/gal)

(2) Example Problem: Calculate the annual VOC emissions for an installation.

COATING TYPE	COATING CONSUMED (gal/yr)	x	EMISSION FACTOR (lb/gal)	=	ANNUAL VOC EMISSIONS (lb/yr)
Paint: Solvent-Base	2000		5.6		11200
Paint: Water-Base	2200		1.0		2200
Enamel	4800		3.8		18240
Lacquer	900		6.5		5850
Primer	2400		6.6		15840
Varnish/Shellac	190		3.5		665
Thinner	1100		7.36		8096
Adhesive	550		4.4		2420
				TOTAL	64511

TABLE F-1 SURFACE COATING VOC EMISSION FACTORS (lb/gal)	
SURFACE COATING	
PAINT: Solvent Base	5.6
PAINT: Water Base	1.3
ENAMEL: General	3.5
LACQUER: General	6.1
PRIMER: General	6.6
VARNISH/SHELLAC: General	3.3
THINNER: General	7.36*
ADHESIVE: General	4.4

*Based on the average density of solvent in coatings.

b. Method 2: This method will provide a more accurate estimation of VOC emissions but requires the weight or volume percentage of the solvents within the surface coating compounds. In addition, the densities of either the coatings or their solvents will be needed. Either of two equations are used, depending upon whether the % solvents within the surface compounds is given in weight or by volume. Frequently, MSDS must be relied upon to provide the data required by these equations. However, inconsistencies and nonuniformity within the present MSDS system may result in data gaps and may require alternate sources for information, including direct contact with manufacturers. Another potential problem can arise when different manufacturers supply the same product with identical stock number and military specification, but each with their own unique MSDS and chemical formula. The following equations are used:

(1) When total solvent % by *weight* is known: $E = CD_1W/100$

(2) When total solvent % by *volume* is known: $E = CVD_2/100$*

Where:

E = VOC emissions (lb/yr)
C = Consumption of surface coating (gal/yr)
W = Weight % of solvent in coating compound (%)
D_1 = Density of coating (lb/gal); if unknown, use table F-2
V = Volume % of solvent in coating compound (%); if unknown, use table F-3
D_2 = Density of solvent (lb/gal); if unknown, use **7.36**

*When adequate information is available, total emissions by a surface coating compound may be estimated by using this equation for each solvent within the compound and summing the results.

Note - Ensure solvents used for clean-up (i.e., MEK) are also calculated IAW section G, "Solvent Cleaning and Stripping."

TABLE F-2 TYPICAL DENSITIES OF COATINGS (lb/gal)					
Coating	Density	Coating	Density	Coating	Density
Enamel, Air Dry	7.6	Enamel, Baking	9.1	Acrylic Enamel	8.9
Alkyd Enamel	8.0	Primer Surfacer	9.4	Primer, Epoxy	10.5
Varnish, Baking	6.6	Lacquer, Spraying	7.9	Vinyl, Roller Coat	7.7
Polyurethane	9.2	Stain	7.3	Sealer	7.0
Magnet Wire Enamel	7.8	Paper Coating	7.7	Fabric Coating	7.7

TABLE F-3 TYPICAL SOLVENT CONTENT (volume %)					
Coating	Solvent %	Coating	Solvent %	Coating	Solvent %
Enamel, Air Dry	60.4	Enamel, Baking	57.2	Acrylic Enamel	69.7
Alkyd Enamel	52.8	Primer Surfacer	51	Primer, Epoxy	42.8
Varnish, Baking	64.7	Lacquer, Spraying	73.9	Vinyl, Roller Coat	88
Polyurethane	68.3	Stain	78.4	Sealer	88.3
Magnet Wire Enamel	75	Paper Coating	78	Fabric Coating	78

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G. SOLVENT CLEANING AND STRIPPING

1. BACKGROUND: Operations involving the use of organic solvents for parts and material cleaning and stripping are widespread on most Air Force installations. Solvent cleaning (or degreasing) operations--for removing grease, oils, soil, and other contaminants--are regularly conducted in aircraft, weapon systems, and vehicle maintenance organizations. Smaller-scale cleaning operations can be found within the Civil Engineering organization and those workplaces associated with communications and electronics maintenance. The use of organic solvents to strip paint and other coatings from parts is common on installations where aircraft maintenance occurs. Fabric dry cleaning facilities utilize organic solvents also. It should be noted that some organic solvents are not considered VOCs by the EPA and are not required to be part of the criteria pollutant inventory. Those not defined as VOCs include methylene chloride, 1,1,1-trichloroethane (methyl chloroform), and others. A complete list of non-VOCs can be found at 40 CFR 50.100.

a. Cleaning/Degreasing: Air Force installations typically utilize two different processes--cold cleaning and open-top vapor degreasers.

(1) Cold cleaning operations involve parts brushing, spraying, flushing, and immersion in containers ranging from small, general purpose cans to automated cleaning vats. Solvents used are typically determined by military specification (Mil Spec) and commonly include stoddard solvent (PD-680), petroleum distillates, and similar products. Alcohols and ketones are frequently specified for use by communications and electronics maintenance shops. There is a growing trend toward replacing traditional organic solvents with compounds that are considered safer and friendlier to the environment. However; at this time, no clear-cut strategy has been developed for testing, approving, and replacing these materials on an Air Force-wide scale.

(2) Open-top vapor systems are batch fed, boiling degreasers that clean with condensation of hot solvent vapor on colder metal parts. Vapor degreasers use halogenated solvents (chlorinated hydrocarbons) including perchloroethylene, trichloroethylene, or 1,1,1 trichloroethane because they are not considered flammable and do not readily volatilize. Many halogenated solvents are not considered VOCs by the EPA and therefore would not be included in a VOC inventory. They may, however, be hazardous air pollutants (HAPs) which must be included in a HAP inventory.

b. Stripping: Heated immersion and/or vapor systems are sometimes used to remove or "strip" aircraft parts of paint, primers, and other coatings prior to reconditioning. Chemical Cleaning, Plating, and Wheel and Tire shops are traditional areas of concern. Compounds containing one or more volatile organic solvents in addition to non-VOC constituents are common with these processes.

c. Fabric Dry Cleaning: These processes may utilize either stoddard solvent, petroleum distillates, or similar, kerosene-like products. Halogenated solvents may also be used, such as perchloroethylene or trichlorotrifluoroethane.

d. Miscellaneous Operations: Unique processes that utilize organic solvents should also be considered, such as the large-scale wipe-down of aircraft sometimes employed by Corrosion Control facilities.

2. CALCULATIONS: Sources to consider for VOC data should include the Hazardous Materials (HAZMAT) Pharmacy Cell, Base Supply, and the Issue Exception (IEX) Coding System. Process information can also be obtained from BEE industrial case files and discussions with workers familiar with their particular operations. A mass balance approach is used for quantifying VOC emissions. Simply, the amount of pure solvent disposed of during the year is subtracted from the amount used within the process during the same time period. Note that for those compounds containing both volatile organic solvents and non-VOC constituents, only the volatile organic solvents (% by weight) are considered.

$$E = (C - W)D^{*}$$

Where:

E = VOC emissions (lb/yr)
C = Amount of VOC solvent consumed/used (gal/yr)
W = Amount of VOC solvent disposed of as waste (gal/yr)
D = Density of the solvent (lb/gal)

*Density = specific gravity (SG) of solvent x 8.33.

3. EXAMPLE PROBLEM: Calculate the annual VOC emissions in a shop that utilizes an automated sprayer vat of stoddard solvent (165 gal/yr). The shop disposes 120 gallons as hazardous waste, the remainder having evaporated.

SOLVENT	SOLVENT USED (gal/yr)	-	SOLVENT DISPOSED (gal/yr)	=	SOLVENT EVAPORATED (gal/yr)	x	SOLVENT DENSITY (lb/gal)	=	ANNUAL EMISSIONS (lb/yr)
PD-680	165		120		45		6.497		292.4

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H. MOTOR VEHICLES

1. BACKGROUND

a. Motor vehicles contribute significantly to the local air pollution load due to their large numbers and around-the-clock emissions generated at ground level. The formula for determining total motor vehicle emissions is relatively straightforward and requires only one variable: vehicle miles traveled (VMT) per year. However, there is no simple strategy for accurately assessing VMT data. The strategies discussed in this section are not considered all-encompassing. EPA's "Mobile 5," a software program for personal computers, is available through EPA's Bulletin Board to assist users in compiling vehicle emissions data. However, the current version is not considered to be user-friendly.

b. Many factors can affect emission estimates considerably including: altitude, average speed, average ambient temperature profile, level of fuel volatility, percentage of VMT in cold/hot start vehicle operation, percentage of travel by vehicle category, air conditioning usage, vehicle load, trailer towing, and humidity. Obviously, the innumerable combinations make it impossible to present emission factors for each application. Therefore, an effort has been made to present emission factors for a set of conditions tailored to represent a typical Air Force community.

c. Emission factors are in grams of pollutant per mile traveled (g/mi) and are based upon EPA studies of the following eight vehicle types:

LDGV - light duty gasoline-fueled vehicles designated for transport of up to 12 people
LDGT1 - light duty gasoline-fueled trucks with a gross vehicle weight (GVW) rating of 6000 pounds or less
LDGT2 - light duty gasoline-fueled trucks with a GVW between 6001 and 8500 pounds
HDGV - heavy duty gasoline-fueled vehicles with a GVW exceeding 8500 pounds
LDDV - light duty diesel-powered vehicles designated for transport of up to 12 people
LDDT - light duty diesel-powered trucks with a GVW of 8500 pounds or less
HDDV - heavy-duty diesel-powered vehicles with a GVW exceeding 8500 pounds
Motorcycles - vehicles with no more than three wheels in contact with the ground and curb weight less than 1500 lbs

2. DATA GATHERING METHODOLOGIES: As a minimum, military-registered privately-owned vehicles (POVs) and government-owned vehicles (GOVs)--also referred to as "fleet vehicles"--must be considered. The first logical step in compiling annual VMT data for an installation is to contact the Civil Engineering (CE) Community Planning or Base Development section. A current traffic study incorporating this data may already exist. If not, the following steps are recommended:

a. <u>POVs</u>:

(1) Contact the Security Police Squadron for assistance in providing the total number of registered vehicles and other pertinent information. It is suggested that a minimum sampling of 5% of the registered vehicle population be used to gather VMT data. To do so, owners should be asked to provide their estimated mileage per day or week on the installation for those designated vehicles only (not for all vehicles registered to the owner). When assessing VMT, remember to consider weekend vs. weekday driving habits.

(2) "Traffic counts" is another method that can be used for determining annual VMT. This method requires a clear-cut strategy tailored to each installation that considers roadway layout, major traffic arteries, and other factors. The complexities of converting data gathered from traffic counts to

VMT can be restrictive and this avenue should not be attempted without consulting the local Community Planner for guidance. The Community Planning/Base Development office may also be able to assist in obtaining traffic counting instruments for the survey.

b. Fleet Vehicles: The Base Transportation Squadron is the source for fleet vehicle data. The organization is responsible for GOV upkeep and maintains records on vehicle type, number of vehicles, mileage, etc. After totaling vehicle mileage for each vehicle *type*, determine what percentage of the total mileage is accumulated off the installation and, if any, subtract this amount [Example: HDDVs (which include buses) may accumulate over 50% of their mileage off-base; LGGVs, no more than 5%].

3. CALCULATIONS: The following equation is used: $E = VFC$

Where:

E = Emissions of a particular pollutant (lb/yr)
V = Vehicle miles traveled (mi/yr)
F = Emission Factor (g/mi)
C = Conversion Factor (2.205×10^{-3} lb/g)

4. EXAMPLE PROBLEMS:

a. POVs: Calculate the annual emissions generated on an installation by the 3280 registered POVs. The installation is located 1150 feet above sea level. The mean average model year for all vehicles is estimated to be between 1987 and 1988. Polling of 5% of the vehicle owners reveals a weekly VMT mean of 15.5 on base. This is considered to accurately reflect the average miles traveled on a weekly basis by all registered vehicles.

POLLUTANT	VEHICLE MILES TRAVELED (mi/yr)	x	EMISSION FACTOR (g/mi)	x	CONVERSION FACTOR (2.205×10^{-3} lb/g)	=	ANNUAL EMISSIONS (lb/yr)
CO	2,643,680		29.09		0.002205		169,575
VOC	2,643,680		4.00		0.002205		23,317
NO_x	2,643,680		2.59		0.002205		15,098
PM	2,643,680		0.085		0.002205		495

b. Fleet Vehicles: Calculate the annual emissions generated on the same installation by all fleet vehicles. The mean average model year for all vehicle types except HDGVs ranges from 1990 to 1991. The average HDGV model year is 1988. Each vehicle type must be assessed independently; therefore, it may be easier to construct a separate table for each pollutant similar to the one below for CO.

VEHICLE TYPE	VEHICLE MILES TRAVELED (mi/yr)	-	%OFF-BASE MILES	x	EMISSION FACTOR (g/mi)	x	CONVERSION FACTOR (2.205×10^{-3})	=	ANNUAL CO EMISSIONS (lb/yr)
LDGV	240,100		10%		20.36		0.002205		9,701
LDGT	485,500		5%		27.42		0.002205		27,886
HDGV	215,200		35%		78.79		0.002205		24,302
LDDV	24,000		5%		1.56		0.002205		78
LDDT	134,500		0%		1.67		0.002205		495
HDDV	148,000		50%		12.29		0.002205		2,005
Total Annual CO Emissions (Fleet Vehicles):									64,467

TABLE H-1 POV EMISSION FACTORS[a] (Grams/Mile) LOW ALTITUDE (≤4000 ft)				
Calendar Year	CO[b]	VOC[c]	NO_x[d]	PM[e]
1988	29.09	4.00	2.59	0.085
1990	24.52	3.41	2.30	0.082
1995	16.58	2.47	1.64	0.078

TABLE H-2 POV EMISSION FACTORS[a] (Grams/Mile) HIGH ALTITUDE (>4000 ft)				
Calendar Year	CO[b]	VOC[c]	NO_x[d]	PM[e]
1988	41.75	4.88	2.34	0.085
1990	33.85	4.08	2.16	0.082
1995	20.60	2.82	1.67	0.078

[a]Federal Test Procedure (FTP) operating mode conditions. Reid Vapor Pressure (fuel volatility) 10.0 psi; 60 - 84°F Diurnal; 80°F Hot Soak (post trip carburator/fuel tank losses); average speed 19.6 mph. SO_x not provided. Emission factors are proportioned sums calculated from EPA-estimated vehicle-miles-traveled (VMT) per each vehicle type for calendar years given.
[b]Exhaust CO.
[c]Combined non-methane VOC (exhaust, evaporative, refueling/running loss emissions).
[d]Exhaust NO_x.
[e]Total particulates.

TABLE H-3 1988 FLEET VEHICLE EMISSION FACTORS[a] (Grams/Mile) LOW ALTITUDE (≤4000 ft)				
Vehicle Type	CO[b]	VOC[c]	NO_x[d]	PM[e]
LDGV	24.59	2.05	1.84	0.022
LDGT[f]	33.13	2.85	2.33	0.022
HDGV	78.79	4.26	5.87	0.102
LDDV	1.59	0.62	1.56	0.20
LDDT	1.77	0.80	1.78	0.260
HDDV	12.94	2.80	19.71	1.652

TABLE H-4 1990 FLEET VEHICLE EMISSION FACTORS[a] (Grams/Mile) LOW ALTITUDE ($\leq$4000 ft)				
Vehicle Type	CO[b]	VOC[c]	NO_x[d]	PM[e]
LDGV	20.36	1.71	1.61	0.022
LDGT[f]	27.42	2.39	2.05	0.022
HDGV	59.83	3.27	5.81	0.102
LDDV	1.56	0.60	1.45	0.20
LDDT	1.67	0.72	1.55	0.260
HDDV	12.29	2.51	18.53	1.652

TABLE H-5 1995 FLEET VEHICLE EMISSION FACTORS[a] (Grams/Mile) LOW ALTITUDE ($\leq$4000 ft)				
Vehicle Type	CO[b]	VOC[c]	NO_x[d]	PM[e]
LDGV	13.20	1.12	1.22	0.022
LDGT[f]	18.49	1.63	1.63	0.022
HDGV	36.39	2.42	4.93	0.102
LDDV	1.40	0.47	1.12	0.20
LDDT	1.52	0.60	1.21	0.260
HDDV	11.22	2.16	10.81	1.652

[a]Federal Test Procedure (FTP) operating mode conditions. Average speed 19.6 mph; ambient temperature 75°F. SO_x not provided.
[b]Exhaust CO.
[c]Exhaust non-methane VOC.
[d]Exhaust NO_x.
[e]Total particulates (includes organics and sulfates).
[f]LDGT includes types I and II.

TABLE H-6 1988 FLEET VEHICLE EMISSION FACTORS[a] (Grams/Mile) HIGH ALTITUDE (>4000 ft)				
Vehicle Type	CO[b]	VOC[c]	NO_x[d]	PM[e]
LDGV	34.33	2.33	1.61	0.022
LDGT[f]	49.50	3.36	2.00	0.022
HDGV	122.15	5.28	4.04	0.102
LDDV	2.27	0.87	1.56	0.20
LDDT	3.70	1.25	1.76	0.260
HDDV	21.21	6.16	19.70	1.652

TABLE H-7 1990 FLEET VEHICLE EMISSION FACTORS[a] (Grams/Mile) HIGH ALTITUDE (>4000 ft)				
Vehicle Type	CO[b]	VOC[c]	NO_x[d]	PM[e]
LDGV	27.27	1.90	1.50	0.022
LDGT[f]	39.34	2.76	1.84	0.022
HDGV	93.95	4.03	4.01	0.102
LDDV	2.07	0.78	1.45	0.20
LDDT	3.25	1.03	1.53	0.260
HDDV	20.26	5.60	18.53	1.652

[a]Federal Test Procedure (FTP) operating mode conditions. Average speed 19.6 mph; ambient temperature 75°F. SO_x not provided.
[b]Exhaust CO.
[c]Exhaust non-methane VOC.
[d]Exhaust NO_x.
[e]Total particulates (includes organics and sulfates).
[f]LDGT includes types I and II.

TABLE H-8 1995 FLEET VEHICLE EMISSION FACTORS[a] (Grams/Mile) HIGH ALTITUDE (>4000 ft)				
Vehicle Type	CO[b]	VOC[c]	NO_x[d]	PM[e]
LDGV	15.58	1.17	1.29	0.022
LDGT[f]	23.87	1.80	1.58	0.022
HDGV	60.63	2.94	3.86	0.102
LDDV	1.52	0.50	1.12	0.20
LDDT	2.61	0.73	1.21	0.260
HDDV	18.69	4.91	10.81	1.652

[a]Federal Test Procedure (FTP) operating mode conditions. Average speed 19.6 mph; ambient temperature 75°F. SO_x not provided.
[b]Exhaust CO.
[c]Exhaust non-methane VOC.
[d]Exhaust NO_x.
[e]Total particulates (includes organics and sulfates).
[f]LDGT includes types I and II.

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I. AIRCRAFT OPERATIONS

1. BACKGROUND: Aircraft operations are segregated into two categories--Ground Operations and Flying Operations--due to the differing data gathering and emission calculating methods involved. Total emissions are determined by combining both categories.

a. Ground Operations: Ground operations involve the functional testing of aircraft engines by the Aircraft Maintenance organization and typically include (1) "trims," which are conducted directly on the aircraft, and (2) engine run-ups with the engine mounted to a test stand, generally in a test cell.

b. Flying Operations: Flying operations include (1) landings and take-offs (**LTO**) and (2) touch-and-go (**T&G**) cycles.

2. CALCULATIONS AND EXAMPLE PROBLEMS: Contact the Aircraft Maintenance organization for ground operations data. Base Operations is typically the focal point for flight operations.

a. Example Problem for Trim Operations: Calculate the annual carbon monoxide (CO) emissions generated by 300 T-38 trim operations (J85-5 engine) conducted over the past year. Maintenance informs you that a typical T-38 trim involves simultaneous operation of both engines and averages a total of 40 minutes at idle power setting, 1 minute at cruise, 5 minutes at military, and 1.5 minutes in afterburn (AB) mode.

- Determine the number of trim operations performed over the past 12 months.

- Verify trim power settings with designations in Table **I-1** (the term "cruise" is not used in Table I-1; however, the fuel flow rate at this setting and discussion with maintenance indicates it correlates most closely with "intermediate").

- Obtain average run/test times at each power setting (convert minutes to hours).

- Obtain emission data from Table **I-1.**

POWER SETTING	HRS/TEST	x	LB/HR/ENG	=	LB CO
Idle	.667		80.10		53.427
Intermediate	.017		62.78		1.067
Military	.083		76.27		6.330
Afterburn	.025		216.32		5.408
Lb CO/Trim/Engine					66.232
No. Engines					x 2
Lb CO/Trim					132.464
Trims/Yr					x 300
Total CO Emissions/Yr (lb)					39,739

- Repeat the calculation steps above for each criteria pollutant.

b. Test Stand Run-Ups: To calculate emissions for test stand run-ups, contact the Test Cell to verify number of run-ups within the past year for the J85-5 engine, average run times at each power setting per engine, then complete the steps as listed above for each pollutant.

c. Example Problem for LTOs: Calculate the annual CO emissions generated by C-141 landings and take-offs (TF33-7 engine).

- Determine total number of LTOs within the past 12 months.

- Verify power settings used with designations in Table I-1.

- Correlate Table I-1 power settings with LTO Procedures in Table I-2. To facilitate comparisons and manageability of data, five standard modes are used.

- Refer to Table I-3 to obtain durations for specific LTO procedures. (Note: Table I-3 should be used as guidance only. If possible, use local data.)

- Obtain emission data (lb/hr) for each engine power setting involved from Table I-1.

ACFT PROCEDURE	POWER SETTING	HOURS	x	LB/HR/ENG	=	LB CO
Taxi/Idle (Out)	Idle	.153		99.51		15.225
Takeoff	Military	.007		6.97		.049
Climbout	Military	.020		6.97		1.506
Approach	Approach	.085		34.25		2.911
Taxi/Idle (In)	Idle	.112		99.51		11.145
Lb CO/LTO/Engine						30.836
No. Engines						x4
Lb CO/LTO						123.344
LTOs/Yr						x 1200
Total CO Emissions/Yr (lb)						148,013

- Repeat the calculation steps above for each criteria pollutant.

d. Touch-and-Go Operations: To calculate T&G emissions, determine number of T&Gs within the past year and perform the steps listed above for each pollutant, but do not calculate the Taxi/Idle (Out), nor Taxi/Idle (In) procedures. Touch-and-Gos include **takeoff**, **climbout** and **approach** modes only. Note that the durations for climbout and approach during T&Gs will typically be shorter because the maximum altitude reached is much lower.

3. JP-8 FUEL CONVERSION

a. Background: Conversions from JP-4 to JP-8 fuel are projected to continue Air Force-wide through 1998. This effort was undertaken to increase survivability of aircrews and aircraft and to standardize fuel type with allies (e.g., NATO). JP-8 is essentially commercial grade Jet A-1 aviation kerosene. Because its vapor pressure is much lower than that of JP-4, the potential for fire and explosion is significantly reduced.

b. Environmental Impact: The emission factors available within this section were obtained from combustor studies employing JP-4 aviation fuel. As of this writing, specific criteria pollutant emission factors for the various flight operation modes are not available for JP-8. However, an environmental impact comparison study specific to the JP-4/JP-8 conversion was conducted by the the Aero Propulsion Laboratory at Wright-Patterson AFB during the 1970s. Much of the following information was derived from that effort:

(1) NO_x production is primarily a function of combustion temperature and is not dependent upon the fuel type. Anticipated change: none.

(2) SO_x production is relative to the sulfur content within the fuel used and can be derived from the following equation:

$$E = CS(2)/100$$

Where:

E = Emissions of SO_x [(lb/hr) as SO_2]
C = Consumption of fuel (lb/hr)
S = Sulfur content of fuel (% by weight)

Note - Sulfur content can vary among fuel sources or distributors, as well as individual fuel shipments. The actual sulfur content of the fuel should be used when available. A typical JP-8 sulfur content of 0.06% (by weight) may be used if the actual content is unknown. The maximum allowable sulfur content in JP-8 (0.3% by weight) can be used for determining "worst case" SO_x emissions.

(3) CO production is a function of combustor design and factors influencing combustion efficiency. Anticipated change: emissions may increase or decrease up to 25% depending primarily upon the specific engine and power settings. The impact is not considered to be significant.

(4) VOC production is a function of combustor design and factors influencing combustion efficiency such as fuel volatility. Anticipated change: emissions are expected to increase slightly in most instances.

(5) Smoke (PM) production is linked primarily to fuel properties such as volatility and aromatic content. Anticipated change: Smoke will increase with JP-8's lower volatility and higher aromatic content (in this instance, the increased smoke is not an indicator of combustion inefficiency). *Note*: Technology is being incorporated into newer engines that significantly reduce smoke.

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TABLE I-1
USAF AIRCRAFT ENGINE EMISSION FACTORS

Pollutant Emissions Per Engine (lb/hr)

ENGINE	POWER SETTING*	FUEL FLOW (lb/hr)	CO	VOC	NO_x	SO_x	PM
F100-100	Idle	1420	34.08	4.54	4.69	1.42	0.17
	Approach	3000	17.40	5.70	20.10	3.0	0.81
	Intermed	5110	8.18	0.51	50.08	5.11	2.40
	Military	10320	9.29	1.03	278.64	10.32	3.50
	AB	46010	184.04	0.46	142.63	46.01	6.90
F100-220	Idle	1040	24.96	3.33	3.43	1.04	0.12
F100-229	Approach	3000	17.40	5.70	20.10	3.0	0.81
	Intermed	5110	8.18	0.51	50.08	5.11	2.40
	Military	10580	9.52	1.06	285.66	10.58	3.60
	AB	51730	206.92	0.52	160.36	51.73	7.76
F101-102	Idle	440	52.84	11.09	3.21	0.44	0.04
	Approach	-	-	-	-	-	-
	Intermed	-	-	-	-	-	-
	Military	9980	75.85	3.99	22.95	9.98	0.20
	AB	66730	1114.39	6.67	306.96	66.73	3.34
F103-100	Idle	1490	119.80	68.39	3.87	1.49	-
F103-101	Approach	11240	60.70	15.74	113.52	11.24	-
	Intermed	-	-	-	-	-	-
	Military	20910	4.18	20.91	710.94	20.91	-
F108-100	Idle	1490	25.44	1.21	4.24	1.49	-
	Approach	2700	9.18	0.27	23.27	2.70	-
	Intermed	7380	6.64	0.30	126.79	7.38	-
	Military	8890	8.0	0.36	187.13	8.89	-
F110**	Idle	1060	25.40	1.10	7.0	1.10	-
	30%	2474	10.50	1.40	23.0	2.50	-
	63%	5523	8.70	1.0	111.0	5.50	-
	Intermed	9954	13.10	1.60	366.0	10.0	-
	AB***	15470	1289.0	1213.0	255.0	15.50	-
F119**	Idle	1200	96.0	48.0	1.32	1.20	-
	40%	5640	62.0	22.56	27.07	5.64	-
	60%	9350	93.5	32.73	102.85	9.35	-
	Military	16700	133.6	50.10	384.10	16.70	-
JT3D-3B	Idle	1110	138.75	125.54	1.78	1.11	0.58
	Approach	4140	39.74	7.87	21.94	4.14	7.99
	Intermed	-	-	-	-	-	-
	Military	9630	10.59	3.85	131.93	9.63	7.32
JT8D-9	Idle	1440	50.11	10.51	4.32	1.44	0.55
	Approach	3410	18.07	1.70	31.03	3.41	1.50
	Intermed	-	-	-	-	-	-
	Military	8630	7.77	0.86	195.04	8.63	3.62
J57-43WB	Idle	990	77.22	74.25	2.18	0.99	0.14
	Approach	1850	44.40	17.02	6.66	1.85	0.54
	Intermed	6690	15.39	0.67	66.23	6.69	8.23
	Military	7780	11.67	0.78	85.58	7.78	13.54
	AB***	12130	254.73	26.69	32.75	12.13	272.93

TABLE I-1
USAF AIRCRAFT ENGINE EMISSION FACTORS (Continued)

Pollutant Emissions Per Engine (lb/hr)

ENGINE	POWER SETTING*	FUEL FLOW (lb/hr)	CO	VOC	NO_x	SO_x	PM
J57-59	Idle	1250	81.25	66.13	3.0	1.25	0.16
	Approach	1850	60.13	26.27	6.11	1.85	0.41
	Intermed	3870	34.44	4.26	23.61	3.87	2.32
	Military	7900	18.96	1.58	89.27	7.90	6.64
	AB***	12130	255.94	26.69	32.75	12.13	272.93
J60-5B	Idle	460	32.20	4.23	0.69	0.46	0.01
	Approach	520	26.26	2.91	0.88	0.52	0.01
	Intermed	1430	8.29	0.29	5.72	1.43	0.33
	Military	2470	9.88	0.25	11.36	2.47	0.42
J69-25	Idle	231	29.80	4.39	0.35	0.23	0.13
	Approach	288	30.79	3.20	0.49	0.29	0.08
	Intermed	700	35.0	0.91	1.89	0.70	0.01
	Military	1100	35.20	0.55	3.96	1.10	0.02
J79-17	Idle	1060	69.96	24.49	2.86	1.06	0.19
	Approach	3500	53.90	1.75	15.75	3.50	1.79
	Intermed	7000	54.60	0.70	40.60	7.0	5.04
	Military	9820	51.06	0.98	104.09	9.82	9.03
	AB	34950	139.80	0.35	108.35	34.95	5.24
J85-5A	Idle	450	80.10	13.50	0.59	0.45	0.01
	Approach	1000	73.60	6.40	1.80	1.0	0.01
	Intermed	1460	62.78	5.11	3.36	1.46	0.02
	Military	2630	76.27	2.10	6.84	2.63	0.05
	AB	8320	216.32	0.58	16.64	8.32	0.07
TF30-103	Idle	827	82.70	63.60	3.30	0.83	-
	30%	2003	72.50	21.90	14.30	2.0	-
	75%	4119	22.70	1.30	62.20	4.12	-
	100%	5541	11.60	0.50	111.0	5.54	-
TF30-109	Idle	864	89.0	51.10	3.70	0.86	-
	30%	2138	59.80	8.10	17.30	2.14	-
	75%	4550	15.40	0.70	71.60	4.55	-
	100%	6246	6.70	0.50	140.0	6.25	-
TF30-111	Idle	950	45.60	18.05	2.76	0.95	0.02
	Approach	2100	20.79	5.67	13.23	2.10	0.17
	Intermed	7160	5.01	0.72	143.20	7.16	2.29
	Military	9080	6.36	0.91	254.24	9.08	2.18
	AB	54000	216.0	0.54	167.40	54.0	8.10
TF33-3	Idle	900	96.30	75.60	1.62	0.90	0.21
	Approach	3800	23.94	9.88	22.04	3.80	3.76
	Intermed	6240	14.35	4.37	53.04	6.24	11.73
	Military	7440	12.65	4.46	74.40	7.44	12.87
TF33-5	Idle	1120	140.0	126.67	1.79	1.12	0.56
	Approach	4140	39.74	7.87	21.94	4.14	7.87
	Intermed	8960	15.23	4.48	95.87	8.96	8.06
	Military	9630	10.59	3.85	131.93	9.63	7.70

TABLE I-1
USAF AIRCRAFT ENGINE EMISSION FACTORS (Continued)

Pollutant Emissions Per Engine (lb/hr)

ENGINE	POWER SETTING*	FUEL FLOW (lb/hr)	CO	VOC	NO_x	SO_x	PM
TF33-7	Idle	1070	99.51	82.39	1.93	1.07	0.12
	Approach	2500	34.25	9.0	9.50	2.50	0.98
	Intermed	7230	9.40	0.72	67.96	7.23	9.40
	Military	8710	6.97	0.26	104.52	8.71	7.93
TF33-100A	Idle	1200	111.60	92.40	1.30	1.20	0.13
	Approach	2500	34.25	9.0	9.50	2.50	0.98
	Intermed	7230	9.40	0.72	67.96	7.23	9.40
	Military	11760	9.41	0.35	141.12	11.76	10.70
TF34-100	Idle	390	41.61	13.38	0.82	0.39	-
	Approach	920	15.0	1.75	5.24	0.92	-
	Intermed	460	35.88	9.34	1.20	0.46	-
	Military	2710	5.96	0.27	29.0	2.71	-
TF39-1	Idle	1130	75.71	26.0	3.40	1.13	0.02
	Approach	1500	58.80	19.80	5.85	1.50	0.02
	Intermed	12020	8.41	2.40	336.56	12.02	0.36
	Military	12690	8.88	2.54	355.32	12.69	0.32
T56-7	Idle	720	23.04	15.12	2.81	0.72	0.59
	Approach	830	18.43	10.29	3.65	0.83	0.81
	Intermed	1850	4.44	0.93	17.02	1.85	0.94
	Military	1960	4.12	0.78	18.23	1.96	0.98
T56-15	Idle	800	25.60	16.80	3.12	0.80	0.66
	Approach	830	18.43	10.29	3.65	0.83	0.81
	Intermed	1850	4.44	0.93	17.02	1.85	0.94
	Military	2300	4.83	0.92	21.39	2.30	1.04

\- Data Unavailable

* Power setting terminology listed here, as originally reported with emission data, may or may not directly correlate with terminology used by maintenance personnel. For example, the terms "cruise" or "high-cruise/low-cruise" are sometimes used. Additionally, personnel may refer to power settings only as percentages of power. To ensure that proper settings and corresponding emission rates above are selected, it is recommended that comparisons be made between the fuel rates used during the actual ground operations and LTO/T&G procedures and those in the **Fuel Flow** column listed here.

** Data assumed to represent all engines with this prefix designation.

*** Afterburner, water augmented.

TABLE I-2 TYPICAL POWER SETTINGS FOR LTO AND T&G CYCLES		
	Power Setting	
Procedure	Military Transport Aircraft	Military Jet Aircraft[a]
Taxi/Idle (out)	Idle	Idle
Takeoff	Military	Military or AB[b]
Climbout	Military	Military
Approach	Approach	Intermediate
Taxi/Idle (in)	Idle	Idle

[a]Includes all aircraft not designated as "transport."
[b]Afterburner for those aircraft so equipped.

TABLE I-3 TYPICAL DURATIONS (Hrs) FOR LTO AND T&G CYCLES[a]					
	Procedure				
Aircraft	Taxi/ Idle Out[b]	Takeoff	Climbout	Approach	Taxi/ Idle In[c]
Transport (B-52 & KC-135R)	0.547	0.012	0.027	0.087	0.248
USAF Transport[d] (General)	0.153	0.007	0.020	0.085	0.112
USAF Combat[e]	0.308	0.007	0.013	0.058	0.188
Trainer (T-38)	0.213	0.007	0.015	0.063	0.107
USAF Trainer[d] (General)	0.113	0.008	0.023	0.067	0.073

[a]Durations are variable. This table is for guidance; if possible, use local data.
[b]Includes startup, taxi, and engine check.
[c]Includes landing, taxi, and shutdown.
[d]Turbine-engined aircraft only.
[e]Fighter/attack aircraft only.

TABLE I-4
USAF AIRCRAFT ENGINE CROSS-REFERENCE

AIRCRAFT	ENGINE(S)	NUMBER OF ENGINES	MANUFACTURER*	REFERENCE**
A/OA-10	TF34-100	2	GE	A
AC-130A/H/U	T56-15	4	AL	A
B-1B	F101-102	4	GE	A
B-52G	J57-43WB	8	PW	A
B-52H	TF33-3	8	PW	A
C-5A/B	TF39-1	4	GE	A
C-9A/C	JT8D-9	2	PW	A
C-130A-E	T56-7	4	AL	A
C-130H	T56-15	4	AL	A
C-135A	J57-59	4	PW	A
C-135B	TF33-5	4	PW	A
C-141A/B	TF33-7	4	PW	A
E-3B/C	TF33-100A	4	PW	A
E-4B	F103-100	4	GE	A
EF-111A	TF30-109	2	PW	B
EC-130E/H	T56-15	4	AL	A
F-4E/G	J79-17	2	GE	A
F-15	F100-100; F100-220; F100-229	2	PW	A
F-16	F100-100; F100-220; F100-229;	1	PW	A
	F110-100; F110-129	1	GE	C
F-22	F119	2	PW	D
F-111A/E	TF30-103	2	PW	B
F-111D	TF30-109	2	PW	B
F-111F	TF30-111	2	PW	A

TABLE I-4
USAF AIRCRAFT ENGINE CROSS-REFERENCE (Continued)

AIRCRAFT	ENGINE(S)	NUMBER OF ENGINES	MANUFACTURER*	REFERENCE**
HC-130H/N/P	T56-15	4	AL	A
KC-10A	F103-100; F103-101	3	GE	A
KC-135E	JT3D	4	PW	A
KC-135R	F108-100	4	CFM	A
MC-130E/H	T56-15	4	AL	A
RC-135E/M	TF33-5	4	PW	A
RF-4C	J79-17	2	GE	A
T-37B	J69-25	2	CT	A
T-38	J85-5A	2	GE	A
T-43A	JT8D-9	2	PW	A
VC-137B/C	JT3D-3	4	PW	A
WC-135B	TF33-5	4	PW	A

*MANUFACTURER
AL - Allison
CFM - CFM International
CT - Continental
GE - General Electric
PW - Pratt & Whitney

**EMISSION DATA REFERENCE
A - Air Force Engineering and Service Center (AFESC) Report ESL-TR85-14
B - AFESC Report ESL-TR-87-27
C - AFESC Report ESL-TR-89-13
D - Aeronautical Systems Center, Wright-Patterson AFB

Aircraft not listed include those without emission data and those being phased out or re-engined.

J. AEROSPACE GROUND EQUIPMENT AND EMERGENCY GENERATORS

1. BACKGROUND

a. Aerospace Ground Equipment (AGE), as referred to in this manual, consists of all motorized aircraft support equipment except for refueling vehicles or those that would otherwise be covered under the section "Motor Vehicles." AGE; generally considered to be mobile sources, include but are not limited to: power generators, compressors, hydraulic test stands, weapons loading units, towing vehicles; and supplementary heating, air conditioning, and lighting units.

b. Emergency Generators are typically powered by reciprocating engines fueled by diesel or gasoline. They are usually fixed in-place and are located throughout the installation to provide supplemental or emergency power to various systems and facilities.

2. CALCULATIONS: The installation's Aircraft Maintenance unit is the primary source for AGE data. The Civil Engineering organization generally tracks and provides maintenance for base emergency power generators. Fuel usage may have to be obtained from Base Supply Fuels.

a. Primary Method: The following equation is used: $E = CF$

Where:

E = Emissions of a particular pollutant (lb/yr)
C = Fuel consumption (e.g., 10^3 gal/yr, 10^6 ft^3/yr)
F = Emission Factor (e.g., lb/10^3 gal, lb/10^6 ft^3)

b. Alternate Method: An alternative method for calculating the emissions of individual AGE types is available in Engineering & Services Laboratory (ESL) Nov 83 Report ESL-TR-83-48, "Aircraft Generation Equipment Emissions Estimator (AGEEE)." The specific AGE and aircraft serviced are required when performing the alternate method. Note: This method does not include all aircraft and AGE.

2. EXAMPLE PROBLEMS:

(a) Calculate the total annual emissions for an installation's AGE turbine air compressors that are powered with JP-8 jet fuel. This equipment consumes 12,000 gallons of fuel annually.

POLLUTANT	FUEL CONSUMPTION (10^3 gal/yr)	x	EMISSION FACTOR (lb/10^3 gal)	=	ANNUAL EMISSIONS (lb/yr)
CO	12		15.4		184.8
VOC	12		4.77		57.24
NO_x	12		67.8		813.6
SO_x	12		6.2		74.4
PM	12		5.0		60.0
PM_{10}	12		4.8		57.6

(b) Calculate the total annual emissions for an installation's reciprocating emergency generators that are powered with diesel fuel. These generators consume 10,500 gallons of fuel annually.

POLLUTANT	FUEL CONSUMPTION (10^3 gal/yr)	x	EMISSION FACTOR (lb/10^3 gal)	=	ANNUAL EMISSIONS (lb/yr)
CO	10.5		130.0		1365.0
VOC	10.5		49.3		517.65
NO_x	10.5		604.0		6342.0
SO_x	10.5		39.7		416.85
PM	10.5		42.5		446.25
PM_{10}	10.5		32.0		336.0

TABLE J-1
AGE AND EMERGENCY GENERATORS
UNCONTROLLED EMISSION FACTORS (lb/unit)

Process	CO	VOC	NO_x	SO_x[a]	PM	PM_{10}
DISTILLATE OIL (Diesel)[b]						
Turbine	15.4	4.77	67.8	140(S)	5.0	4.8
Reciprocating	130.0	49.3	604.0	39.7	42.5	32.0
KEROSENE/NAPHTHA[c] (Jet Fuel)						
Turbine	15.4	4.77	67.8	140(S)	5.0	4.8
Reciprocating	102.0	32.1	469.0	31.2	33.5	32.0
GASOLINE (Mogas)[d]						
Reciprocating	7128.0	344.0	185.0	9.5	11.4	6.2
NATURAL GAS[e]						
Turbine	120.0	6.9	300.0	0.6	14.0	14.0
Reciprocating	430.0	82.9	3400.0	940(S)	10.0	10.0
LIQUIFIED PETROLEUM GAS[f] (LPG)						
Reciprocating	129.0	83.0	139.0	0.35	5.0	5.0
RESIDUAL/CRUDE OIL[g]						
Reciprocating	102.0	32.1	469.0	155(S)	33.5	30.8

[a]"S" indicates that the weight % of sulfur in fuel should be multiplied by given value. Contact Base Supply Fuels/POL for this data. [b]Units:
[b]Units: 1000 gallons burned. Reciprocation emission factors based on a fuel density of 7.1 lb/gal and a fuel heating value of 19,300 BTu/lb.
[c]Units: 1000 gallons burned.
[d]Units: 1000 gallons burned. Emission factors based on a fuel density of 5.6 lb/gal and a fuel heating value of 20,300 BTu/lb.
[e]Units: million cubic feet (10^6 ft^3) burned.
[f]Units: 1000 gallons burned. Applies to both butane and propane.
[g]Units: 1000 gallons burned.
[h]Units: 1000 gallons burned.

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(U.S.) Environmental Protection Agency. Factor Information Retrieval (FIRE) System. Research Triangle Park NC, September 1993.

Berlinrut, D.D., Ramos, L.A., Seitchek, G.D. Aircraft Generation Equipment Emissions Estimator (AGEEE). ESL-TR-83-48, November 1983.

APPENDIX A

Air Emission Compliance Resources

Publications

EPA's "Compilation of Air Pollutant Emission Factors" (AP-42) may be obtained from: Superintendent of Documents, Government Printing Office (GPO), Washington DC 20402-9325, Tel (202) 783-3238.

The quarterly newsletter "Chief," EPA's clearinghouse for information pertaining to air emission factors and inventorys, can be obtained from: U.S. Environmental Protection Agency, Emission Inventory Branch (MD-14), Research Triangle Park NC 27711, Tel (919) 541-5285

Bulletin Board

EPA's Office of Air Quality Planning and Standard's Technology Transfer Network (OAQPS TTN) offers an electronic bulletin board continuously updated with the latest information, technology, and tools on air pollution control. Access is free and available 24 hours a day (except Monday, 8-12 a.m. EST). Access can be made through **Telnet ttnbbs.rtpnc.epa.gov** or by calling (919) 541-5742 through your modem (1200/2400/9600 baud). For additional information and initial set-up, call (919) 541-5384.

EPA Software

The following programs are available to assist in compliance requirements governing criteria and hazardous air pollutants (HAPs).

- *AFSEF:* AIRS Facility Subsystem Emission Factors Database (criteria pollutant emission factors for stationary point sources)
- *TANKS:* Storage Tank Emissions Calculations
- *SPECIATE:* Volatile Organic Compound/Particulate Matter Speciation Database Management System
- *FIRE:* Factor Information Retrieval System
- *Air CHIEF (CD-ROM):* (contains AP-42, SPECIATE, FIRE, and the report series "Locating and Estimating Air Emissions")

Federal agencies may obtain a free copy of AFSEF from: U.S. EPA, National Air Data Branch, Research Triangle Park NC 27711, Tel (919) 541-5456. Copies of the other programs are available through: U.S. EPA, Emission Inventory Branch (MD-14), Research Triangle Park NC 27711, Tel (919) 541-5285. Most of these programs/databases can also be accessed and downloaded from the OAQPS TTN Bulletin Board.

Air Emissions Management Software

The following two emissions management programs are approved for Air Force use to store, manage, and report air emissions data. Both programs are available at no cost. User manuals are furnished; however, if it is determined that hands-on training is desirable, training can be arranged for a fee. Both programs require a dedicated personal computer. Additional information on specifics, hardware requirements, and training can be obtained by contacting the POC's listed below.

AQUIS: Air Quality Utility Information System

This program is being promoted and distributed by AFMC and ACC within their commands. The development of AQUIS was spearheaded by HQ AFMC/CEV, who presently remains the Air Force POC. The developing contractor is Argonne National Laboratory. Program capabilities include emission calculations for criteria pollutants and HAPs, some modeling, and management of stationary point source data and emission permits. The system presently does not manage mobile source data. AQUIS is slated for interface with WIMS-ES to allow up-channel reporting to the Air Staff level electronically. Commands acquiring AQUIS have been focusing operation and management on CE Environmental Managers (CEV) at the installation level, although training courses have included Bioenvironmental Engineering personnel. If operated by the local CEV, inputs by Bioenvironmental Engineering may still be required. The POC for AQUIS is:

S. James Ryckman
HQ AFMC/CEVC
4225 Logistics Ave., Suite 8
Wright-Patterson AFB, Ohio 45433-5747

Tel: DSN 787-5879 or Comm (513) 257-5879
FAX: DSN 787-5875 or Comm (513) 257-5875

AFAECTS: Air Force Air Emission Compliance Tracking System

AFAECTS was completed and delivered to SPACECOM in October 1993. The program was initiated by AFSPACECOM/SGB and developed by Pacific Environmental Services, Inc. (PES). Intended for use by installation-level Bioenvironmental Engineering offices, the program was designed to calculate, organize, and generate reports of criteria and HAP air emission data for installation point, area, and mobile sources. Permit managing capabilities are also included. PES is under agreement to provide AFAECTS to Air Force users at no cost. POC for AFAECTS is:

Richard Rehm
Pacific Environmental Services, Inc.
5001 South Miami Blvd.
P.O. Box 12077
Research Triangle Park, NC 27709-2077

Tel: (919) 941-0333
FAX: (919) 941-0234

APPENDIX B

Useful Properties/Characteristics of JP-8 Fuel

USEFUL PROPERTIES/CHARACTERISTICS OF JP-8 FUEL FOR PERFORMING AIR EMISSION INVENTORIES

Property	Specification Requirement	Typical Value
Net Heat of Combustion (Btu/lb)	≥ 18,400	18,600
Specific Gravity*	0.755-0.830	0.810
Sulfur Content (wt%)	≤ 0.3	0.06
Molecular Weight (lb/lb-mole)	---	152.0
Reid Vapor Pressure (psi)	---	0.203

*Density (lb/gal) = Specific Gravity x 8.33

Vapor Pressures at Various Temperatures

Temperature (°F)	40	50	60	70	80	90	100
Vapor Pressure (psi)	0.017	0.025	0.033	0.046	0.062	0.083	0.107

Hazardous Air Pollutant Compounds Found in Liquid JP-8 (Concentrations from 6 different fuel samples analyzed at the Wright-Patterson AFB Fuels Laboratory)

Compound	Low Concentration (ppm by wt)*	High Concentration (ppm by wt)*	Average Concentration (ppm by wt)*
Benzene	10	61	38
Ethylbenzene	226	1472	671
Hexane	14	192	81
Toluene	103	898	410
Xylenes (o,m,p)	824	2953	2023

* Weight % = ppm/10^4

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